GEOLOGY AND GEOCHEMISTRY OF THE MUSKOKA-HALIBURTON STUDY AREA

D.S. Jeffries and W.R. Snyder

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DATA REPORT SERIES

The data presented in this report were collected by staff of the Water Resources Branch of the Ontario Ministry of the Environment as part of the Lakeshore Capacity Study or the Acid Precipitation in Ontario Study. This unreviewed report does not necessarily reflect the views or opinions of the Ontario Ministry of the Environment.

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Data Report DR 83/2

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PREFACE

The unpublished Data Report Series is intended as a readily available source of basic data collected for lakes and watersheds in the Muskoka-Haliburton area of Ontario. These data were collected as part of the Lakeshore Capacity Study and/or the Acid Precipitation in Ontario Study.

The limnological portion of the Lakeshore Capacity Study (1975-81) was initiated to investigate the relationships between lakeshore development and lake trophic status in low ionic strength Precambrian lakes. The Acid Precipitation in Ontario Study (1979-present) was initiated, in part, to investigate the effects of the deposition of strong acids on aquatic and terrestrial ecosystems in Ontario. The primary findings of these studies have been and will continue to be published as reviewed papers and technical reports.

ABSTRACT

The geology of the Muskoka-Haliburton area is described. Discussion of the relationship between geochemistry and lake water chemistry is presented, as well as background information on the geological history of the area and the regional bedrock and surficial geology. The bedrock geology reflects the Precambrian processes which formed the Canadian Shield, while the surficial geology is primarily the result of recent Pleistocene glaciation. Intensive mapping of the basins under study has shown that the bedrock geochemistry can be very variable over the entire study area but is reasonably uniform within the basin of any given lake. On the other hand, surficial geology is highly variable ranging from bare bedrock to thick sand deposits. Till of variable thickness is the principal type of surficial deposit. Data are presented giving the areal extent of each surficial deposit and bedrock type in the subwatersheds of the six "A" lake basins, nine "B" lake basins, and nine "export" stream basins.

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I. INTRODUCTION

The purpose of this report is to provide background information regarding the geological history, regional and local bedrock and surficial geology of the Muskoka-Haliburton study area and discuss their influence on the observed water quality. Specific information for the six principal lakes under study ("A" lakes), the secondary study lakes ("B" lakes), and export stream watersheds as well as an overall summary of soil chemistry will be presented.

II. GEOCHEMISTRY AND LAKE WATER CHEMISTRY

As part of the overall cycle of matter, the hydrosphere participates first, as a conveyor of material both in dissolved and suspended forms and second, in chemical transformation of matter. Hence, lake and stream chemistry reflects the interaction between atmospheric acids and oxidants and lithologic materials. Such weathering reactions fall into three main categories:

a) Congruent dissolution reactions, for example

$$\underset{\text{(calcite)}}{CaCO_3} + H_2O + CO_2 \rightarrow Ca^{++} + 2HCO_3^- \quad (1)$$

b) Incongruent dissolution reactions, for example

$$\underset{\text{(biotite)}}{KMg_3AlSi_3O_{10}(OH)_2} + 15/2\ H_2O + 7\ CO_2 \rightarrow$$

$$K^+ + 3\ Mg^{++} + 7\ HCO_3^- + 2\ H_4SiO_4 + 1/2\ \underset{\text{(Kaolinite)}}{Al_2Si_2O_5(OH)_4} \quad (2)$$

c) Redox reactions, for example

$$FeS_2 + 15/4\ O_2 + 7/2\ H_2O \rightarrow Fe(OH)_3 + 4H^+ + 2\ SO_4^= \quad (3)$$

The first two reaction types are acid-base interactions, equation one being typical of weathering occurring in areas dominated by carbonate rocks and equation two typical of areas dominated by silicate rocks. The

acid reactant in both cases is atmospheric carbonic acid ($H_2O + CO_2$). Historically, this acid has been the principal driving force in weathering reactions which is reflected in bicarbonate being the principal anion in most freshwater systems. Within the study area, and in fact on a global scale, the weathering of silicates (incongruent dissolution) is the most important among the weathering reactions and is characterized by the production of a secondary mineral (clay) which must necessarily have a higher acidity than the parent silicate. Redox reactions, such as equation three are of minor importance but are noteworthy since acid is produced rather than consumed as in the previous reaction types.

Bricker and Garrels (1967) have examined the relative influence of these weathering reactions on water composition in a global context and conclude that calcium, bicarbonate, hydrogren ion and perhaps magnesium are controlled by the congruent dissolution of carbonate rocks. Sodium, potassium, silica, and possible calcium and magnesium are controlled by the incongruent dissolution of silicates that make up 70% of the rock in contact with streams and groundwaters. Other chemical and biological reactions further mediate the water composition, thereby yielding the observed concentration ranges and variability.

In many areas, carbonic acid in precipitation is no longer the principal weathering agent, but has been replaced by stronger acids (nitric and sulphuric) from anthropogenic sources. The occurrence of acidic precipitation of this type in the study area has been noted by Dillon et al. (1978). Because of this phenomenon, weathering rates may be expected to increase, gross chemistry of streams and lakes to change, and sulphate to play an increasingly important role relative to bicarbonate.

III. GEOLOGICAL HISTORY

The study area is located near the southern fringe of the Canadian Shield, a large region of Precambrian bedrock that covers nearly half of Canada. The geology of the area is the result of two highly time-divergent processes; first, rock formation and orogenic (mountain

building accompanied by folding) alteration during Precambrian times, and second, erosion and eventually Pleistocene glaciation. (See Table 1 for geologic time scale and Figure 1 for a schematic of the geological history.)

The Precambrian period of time extends from approximately 570 million years before the present (mybp) back to the earliest known rocks, ≃ 3,500 mybp. The Precambrian period has been divided into two eras - the Archean (≃2,500 - 3,500 mybp) and the Proterozoic (≃570 - 2,500 mybp). Throughout this period of time the bedrock of the Canadian Shield was formed and altered to yield the rock types and most of the physiography observed today. During the Precambrian, the Shield was affected at various locations by four distinct orogenic events, however, it is the most recent of these - the Grenville orogeny, 955 mybp - which has affected the Muskoka-Haliburton region to the greatest degree. Between each event erosional intervals smoothed and lowered the landscape.

The Archean era was a time of intense volcanic activity and of deposition of thick sedimentary sequences, most of these being clastic sediments (accumulations of particulate material as opposed to precipitated material). All of these rocks were then folded and metamorphosed to some degree, and intruded by granitic rocks during the Kenoran Orogeny - a sequence followed three more times during the Precambrian.

Sedimentary rocks deposited during the Proterozoic show a marked change in depositional environments with much better sorting and much more limestone (a precipitated sediment) than those of the Archean. The Hudsonian (1,735 mybp) and Elsonian (1,370 mybp) orogenies primarily affected the extreme northwest and northeast portions of the Shield respectively, although some of the metamorphic rocks of the Hudsonian and the intruded basic and granitic rocks of the Elsonian have also been identified in the Grenville province.

The Grenville province of the Canadian Shield is a rectangular strip of land approximately four hundred kilometers wide and nearly two thousand kilometers long trending southwest to northeast from

Table 1: The geologic time scale (from Krauskopf 1967).

Era	Period	Epoch	Time Before Present (10^6 yr)
PHANEROZOIC			
Cenozoic	Quaternary	Recent	0.01
		Pleistocene	2
		Pliocene	10
		Miocene	27
		Oligocene	38
		Eocene	55
		Paleocene	65-70
Mesozoic	Cretaceous		130
	Jurassic		180
	Triassic		225
Paleozoic	Permian		260
	Pennsylvanian		310
	Mississippain		340
	Devonian		405
	Silurian		435
	Ordovician		480
	Cambrian		550-570
PRECAMBRIAN			
Proterozoic			2,500
Archean			3,500

Figure 1: Schematic of the geologic history of the study area

Geologic Time* (millions of years before the present)	Geologic Event	Processes
3,500 (?)		- Deposition of volcanics and clastic sediments
Arkean Era		
2,480	Kenoran Orogeny	- Rock metamorphism, folding, and intrusion by granite rocks followed by long erosional period
1,735	Hudsonian Orogeny	- Orogenic episodes separated by substantial erosional intervals
1,370	Elsonian Orogeny	- Sediments deposited at this time are better sorted than Archean sediments and have significant occurrence of limestone
Proterozoic Era		
955	Grenville Orogeny	- Major deformational events in the study area (folding, faulting, metamorphism, intrusion by granitic and diabasic rods) - Most evidence of previous geologic events was obliterated by the Grenville deformation - Crustal stabilization
550-260 Paleozoic Era – Mesozoic Era		- Sediment deposition during the Paleozoic
0.1	Glaciation	- Subareal erosion
	(Wisconsin predominant)	- Glacial erosion of Paleozoic sediments(?) and rounding and polishing of Precambrian bedrock - Deposit of glacial deposits
Cenozoic Era		
0.01		- Glacier recession and isostatic rebound resulting in development of several different drainage systems
0	Present Inter-Glacial Period	- Subareal erosion and glacial lacustrine sedimentation

*Note: Time scale is not linear.

Georgian Bay to the Labrador Coast. A small portion also extends into the Adirondack region of the United States. Hence the study area is wholly located within this geological province which was most affected by the last Precambrian orogeny. The Grenville orogeny was accompanied by extensive folding (commonly along a northwest to southeast axis), faulting (some trending northwest to southeast, others at right angles to this), metamorphosis of existing sediments and volcanics, and intrusion by granitic and occasionally more basic rocks. Both the folding and faulting have resulted in currently noticeable physiographic features. For example, the series of northwest to southeast trending ridges in Muskoka is the result of differential erosion of folded rocks, while several scarps and lowlands may be attributed to faults. The shape of many lakes and direction of stream flow is also influenced by these late Precambrian or early Paleozoic faults.

After the Grenville orogeny, the bedrock stabilized and is now one of the most seismically inactive areas in the world. Because of this fact, their age, and the high probability of their existence under the Paleozoic surface rocks to the south, they are commonly referred to as "the stable basement rock of North America."

Topographically, the study area is part of a large dome resulting from the broad up-warping of the land along two axes at right angles (NW-SE and SW-NE). These "anticlinal" forms presumably also developed in response to the Grenville orogeny. Long term differential erosion has resulted in local relief on the order of 15-60 meters. Typical landscape includes rocky knobs and ridges separated by lakes and/or swampy lowlands with non-dendritic drainage patterns attributable to structural control. Occasional inliers of Paleozoic rock show that there was a time of sediment deposition after the Grenville orogeny. However, the present terrain makes it clear that subareal erosion was the dominating factor from the Precambrian to the Quaternary.

The long period of erosion was interrupted by a relatively short but significant period of glaciation during the Pleistocene. Although four distinct periods of glaciation are known, the major effects and currently observed features in the study area can be attributed to the last - the

Wisconsin glaciation which lasted approximately from 100 to 7 thousand years before the present. Glacial erosion has been responsible for the rounding and polishing of the rock knobs and ridges, (thereby lowering the relief) scouring of many basins now occupied by lakes, and re-deposition of numerous types of glacial debris. Depending on the characteristics of the glacier's advance or withdrawal, basal tills, moraines, eskers, outwash terrace and lake sediments were deposited on the essentially clean bedrock surface. These will be discussed in more detail in following sections. Many of these were eroded and partially redistributed by the meltwaters accompanying the final glacial retreat. The drainage pattern exhibited by the meltwaters is very complex owing to isostatic rebound, that is, the direction of drainage changed many times in response to uplift of the earth's crust once the immense glacial weight was removed.

At present, approximately one third of the area is exposed bedrock or covered by extremely thin drift (a few centimeters). The remaining two thirds is primarily covered by thicker till deposits with significant occurrences of clay and sand plains interspersed with hills or ridges of sand and gravel.

Further detail in this geologic history may be found by consulting Stockwell et al. (1970) for the Canadian Shield as a whole, and Chapman (1975) for the Georgian Bay - Ottawa Valley area in particular. The Chapman report particularly stresses Quaternary history - glacial deposits, recession of the Wisconsin glacier and associated development of past and present drainage systems. Prest (1970) gives an overview of the Quaternary geology of Canada including maps and a discussion describing the Wisconsin recession from the Great Lakes region (p. 714-725).

IV. REGIONAL GEOLOGY

1. Bedrock Geology

As mentioned previously, the Lakeshore Capacity Study is located within the Grenville Province which is distinguished by the presence

of certain metasedimentary and metavolcanic rocks. The largest proportion of these rocks are of granitic composition, usually granite gneisses and migmatites while marbles, quartzites, amphilbolites and various igneous intrusives (pegmatites, diorites, ultrabasics, etc.) are of lesser importance. To a geologist, rock type immediately conveys information regarding the petrography, mineralogy and geochemistry of the rocks. However, since it is expected that most readers will not have this background knowledge, the following discussion will explain the processes which have resulted in their current mode of occurrence.

1a. Metamorphism

Three major rock classes are recognized for the purposes of classification - igneous, sedimentary and metamorphic. Igneous rocks are composed of minerals stable at temperatures and pressures in the range 700-1100°C and 1-10,000 atmospheres respectively. In most cases, the minerals were probably in a condition approaching mutual chemical equilibrium when crystallizing from a silicate-melt phase. Sedimentary rocks on the other hand are the product of weathering and precipitation processes (from aqueous solutions) at low temperature and pressure. Both sedimentary and many igneous rocks (particularly volcanics) now lying at depths of 3-20 kilometers are subjected to conditions markedly different (100-600°C and few thousand atmospheres pressure) from those under which they were formed. Igneous and sedimentary rocks are not in a state of internal equilibrium, and under favourable conditions may re-adjust mineralogically or structurally to the temperature and pressure of their situation. Thus, metamorphic rocks are the end-product of such re-adjustment that has taken place in an essentially solid rock, i.e., without the development of a liquid phase.

When metamorphism has reached completion (i.e., chemical and structural equilibrium re-etablished), the nature of the resultant rocks depends on first, the overall chemical

composition (which should be similar to that of the parent material), and second, the temperature and pressure conditions of metamorphism. The degree of metamorphism is reflected in its "grade" with low grade metamorphism altering the rock only to a small degree, while high grade metamorphism causes major changes such as alignment of certain mineral species, segregation of mineral species, development of "saccharoidal" (granular) textures, etc. The bedrock in the Lakeshore Capacity Study area has experienced high-grade metamorphism, i.e., conditions of moderate to high temperature and pressure.

The effect of pressure is variable depending on whether it is a confining pressure (i.e., operating equally in all directions and determined largely by depth) or a directed pressure operating in one particular direction (i.e., a shear stress). The appearance of the resultant rock will be strongly dependent on which pressure type predominates; in the Lakeshore Capacity Study area a directed pressure was most important.

The type of metamorphism found in Muskoka-Haliburton is usually known as "regional metamorphism", being typically developed over areas of many thousands of square kilometers in the root region of fold mountains, and usually found in Precambrian terrains. As discussed in the previous section, this area was affected by at least four orogenic (fold mountain building) events followed by near continuous erosion for a very long time (i.e., since the Precambrian) thereby allowing exposure of the mountain roots. There is not unanimous agreement with respect to the nature and causes of regional metamorphism resulting in large scale deformation and emplacement of granitic* rock. It

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*The terms "granitic" implies that the rocks are of the "acid" class, i.e., having sodium and particularly potassium as their predominant cations. Acid rock types range from granite proper to granodiorite and quartz diorite. "Basic" rocks contain a higher proportion of calcium, iron, and magnesium.

is probable, however, that at great depth below orogenic zones, periodic heat concentrations have supplied the energy necessary for folding, metamorphism, and intrusion of granitic magmas, all more or less contemporaneously.

The combination of temperature and pressure may reach the point where streaks of granitic melt develop by partial fusion of the metamorphic rocks - a borderline condition between metamorphic and igneous processes. The liquid phase may be either squeezed away from the unfused metamorphic residue and intruded into other host rock as veins or larger masses known as dikes and sills, or the quantity of liquid may just build up until it is sufficiently great that the entire mass (part liquid, part crystalline) may become mobile enough to move bodily as a magma. Such processes are used to explain the occurrence of migmitites, rocks composed of metamorphic host material which are streaked and veined with granite. Both situations tend to alter the appearance (more correctly the "fabric") of the host rock, often yielding the "swirled" texture common of migmitites in Muskoka-Haliburton.

1b. Metamorphic Fabric

The fabric of metamorphic rocks forms as the result of the growth of crystals (usually of several different mineral species competing with one another for space) in a continuously solid medium. Textural details are primarily related to the physical properties of the mineral species, particularly those dealing with rate of crystal growth and the relative stability of boundary surfaces. Such properties vary not only between minerals but from one direction to another within an individual crystal. Rock composition permitting, particular temperature and pressure conditions may be expected to preferentially develop certain mineral species in metamorphic rocks. Hence the presence of rutile, magnetite, tourmaline, garnet, chlorite, talc and many others is more common in metamorphic rocks than in other rock types. It should also be noted

however, that various micas, amphiboles, feldspars and quartzes generally make up the primary rock forming minerals in metamorphic rocks just as they do in igneous rock although their crystal "habit" within the rock fabric may be substantially different (particularly for the first two).

An obvious feature of the regional metamorphosed rocks in Muskoka-Haliburton is the presence of "foliation". Sometimes referred to as "schistosity", this term may be applied to any parallel structure that induces a more or less planar fissility in a rock. It is almost always present in rocks that have been deformed during metamorphism. Foliation is generally manifested in response to a shear stress in several or all of the following occurrences:

1) a tendency for tabular micaceous minerals and prismatic amphibole minerals to be oriented with their greatest dimensions roughly parallel to the plane of foliation.

2) an even stronger although less easily recognized tendency for most minerals to have a preferred orientation crystallographically even though their external form may be completely irregular.

3) laminated structure resulting from the segregation of simple mineral assemblages of contrasting mineral composition into alternating layers; this "gneissose" structure should not be mistaken as bedding inherited from the parent rock.

4) parallel alignment of linear elements of the fabric (particularly by prismatic amphibole minerals) in some direction within the foliation.

This very brief discussion on metamorphism should give some understanding of the conditions under which the bedrock in the study area has reached its present condition. Further general

discussion on metamorphism may be found in Turner and Verhoogen (1960).

1c. Rock Types, Minerals, and Characteristics

The following bedrock types have been identified in the Lakeshore Capacity Study area by Hewitt (1967), Chapman (1975), or ourselves. (Note: not in order of importance)

1) Granite gneiss - commonly referred to as paragneiss or pelitic gneiss, this rock is primarily composed of biotite, quartz, and microcline - or plagioclase-feldspar. Horneblende (an amphibole) and garnet are common in small amounts. These gneisses have formed by the regional metamorphism of aluminous sediments (clays, shales, and mudstones). They are medium grain-sized, equigranular (i.e., all mineral grains about the same size) and have a pronounced banded structure which is often highly deformed by folding.

2) Migmitite - the origin of migmatites has been discussed earlier. The host rock that has been injected with granitic material containing mainly quartz and feldspar may be either granitic gneiss (as above) or amphibolite (as below). In many cases it is difficult to distinguish between a poorly developed migmatite and a poorly developed gneiss.

3) Schist - schist may be distinguished from gneiss by its lack of mineralogical banding although it still possesses a marked textural foliation. Relative to the genesis of gneiss, schist may form in response to regional metamorphism of lower grade, or due to compositional constraints. This second reason is probably most important in Muskoka-Haliburton since inter-layered gneiss and schist have been found. Biotite, quartz and feldspar are the dominating minerals.

4) Acid intrusives - much of the bedrock is "cross-veined" with granitic (often referred to as "acid") intrusive rocks characterized by their light colour, quartz and feldspar mineralogy, and frequently large crystal size. Although often loosely referred to as "pegmatites" only a few of these may be correctly labelled in this fashion since a true pegmatite is a product of the end-stages of magmatic differentiation, often having a very unusual geochemistry and rare secondary minerals.

5) Quartzite - when an extremely quartz-rich rock such as a pure sandstone is metamorphosed, a quartzite results. Quartzite is composed of irregular quartz grains (0.1-0.5 mm) fused together along with minor biotite, horneblende, and feldspar. Due to the crystallographic characteristics of quartz, the obvious foliation observed in many metamorphic rocks is not present in quartzite. Colour may be variable and is usually dependent on the type and quantity of chemical impurities (relative to SiO_2) present in the rock.

6) Meta-Arkose - results from the metamorphism of an impure sandstone or other quartz-rich rock. Hence it is similar in appearance to quartzite (i.e., being principally quartz) but contains a small but significant amount of alumino-silicate minerals, notably feldspar and biotite.

7) Marble - results from the metamorphism of limestone and dolomite and commonly contains large calcite crystals in an overall massive structure. It weathers much more easily than the other silicate rocks present in the area. Comments regarding foliation and colour are the same as for quartzite.

8) Amphibolite - medium-grained equigranular rocks composed predominantly of horneblende and plagioclase (oligoclase feldspar). Minor minerals include quartz, biotite,

pyroxenes, and garnet. Amphibolites form from the metamorphism of more basic rocks (i.e., containing more Ca, Fe, and Mg than granitic "acid" rock) whether of sedimentary or igneous origin. Alignment of the horneblende prisms gives amphibolite a characteristic lineation.

9) Diorite - found in a variety of locations, diorite is an intruded igneous rock (plutonic) of basic composition with plagioclase, amphiboles and pyroxenes as the primary minerals and a lesser amount of quartz and minor biotite. It generally has a medium grain size and a typical speckled appearance, is equigranular, and, of course, is not foliated since it is of igneous origin.

10) Gabbro - a few small occurrences of intruded "basic" igneous rock have been found. These gabbroic rocks are predominately composed of horneblende and plagioclase, not foliated, and "cross-cut" boundaries within the host rock. They have an overall dark appearance in contrast to the speckled appearance of diorite.

11) Ultramafic (or ultrabasic) rocks - a minor occurrence of rocks almost completely composed of pyroxene and olivine with some plagioclase has been noted. Hence these rocks are extremely rich in Fe and Mg, are characteristically dark in colour and normally weather very quickly.

1d. Bedrock Geochemistry

A summary of the major bedrock forming minerals noted in the previous section and their theoretical compositions (i.e., assuming no impurities or no compositional variation) is given in Table 2. The chemical composition of several rocks from study watersheds and the Leslie M. Frost Natural Resource Centre which are probably typical of those found throughout Muskoka-Haliburton is given in Table 3. In addition the average composition of Canadian Shield rock (Shaw et al. 1976)

Table 2: Summary of the major rock forming minerals present in Muskoka-Haliburton

Mineral (Group)	Occurrence	Composition
Quartz	Gneiss, Migmatite, Amphibolite, Acid Intrusion, Quartizite Diorite (small)	SiO_2
Feldspar	Gneiss, Migmatite, Amphibolite, Acid Intrusions, Diorite	Orthoclase $(K,Na)Al\ Si_3O_8$ Microcline $K\ Al\ Si_3O_8$ Albite $Na\ Al\ Si_3O_8$* Anorthite $Ca\ Al_2Si_2O_8$*
Mica	Gneiss, Migmatite, Acid Intrusions	Muscovite $K\ Al_2(OH)_2(Al\ Si_3O_{10})$ Biotite $K_2(Mg,Fe)_2(OH)_2(Al\ Si_3O_{10})$
Amphibole	Gneiss (small), Migmatite, Diorite, Amphibolite	Horneblende $Ca_2(Mg,Fe,Al)_5(OH)_2[(Si,Al)_4O_{11}]_2$
Carbonate	Marble	Calcite $CaCO_3$ Dolomite $(Ca,Mg)CO_3$
Pyroxene	Diorite	Enstatite $MgSiO_3$ Augite $Ca(Mg,Fe)(SiO_3)_2$ $[(Al,Fe)_2O_3]_x$
Garnet	All metamorphic rocks in minor amounts	Almandite $Fe_3Al_2(SiO_4)_3$

*Albite and Anorthite are the end-members of a complete solid solution series of minerals that make up the Plagioclase feldspars.

Table 3: Chemical composition (10^4 ppm) of bedrock samples from various study watersheds

Rock Type	Element												
	O	Si	Al	Fe	Ca	Na	Mg	K	Ti	H	P	Mn	C
Biotite Gneiss[1]	49.1	35.0	6.7	1.5	1.0	2.0	.64	3.8	.14	0.0	.04	.04	0.0
Biotite Gneiss[2]	48.3	33.6	7.4	1.7	1.2	2.3	.38	5.0	.18	0.0	.01	.03	0.0
Meta Arkose[3]	48.0	31.4	8.1	2.7	.7	2.9	.74	4.6	.64	0.0	.13	.04	0.0
Migmitite[4]	54.3	29.7	4.3	3.5	1.5	.4	.39	5.4	.39	0.0	.03	.06	0.0
Migmitite[4]	47.2	31.7	7.1	3.8	1.4	2.9	.28	5.0	.41	0.0	.07	.11	0.0
Migmitite[4]	47.2	27.8	8.3	5.7	3.1	2.8	2.2	2.4	.50	0.0	.08	.14	0.0
Mangerite[7]	51.8	28.3	5.3	2.2	2.1	6.0	.83	3.2	.20	0.0	.03	.06	0.0
Diorite[5]	54.3	27.4	7.9	7.9	4.9	2.5	1.9	.60	.38	0.0	.03	.12	0.0
Meta-Gabbro[2]	43.1	20.7	7.2	11.8	6.4	2.5	3.9	.97	2.4	0.0	.86	.16	0.0
Meta-Gabbro[7]	50.0	17.8	2.8	16.0	3.7	3.8	4.9	2.2	2.8	0.0	.23	.19	0.0
Meta-Gabbro[7]	38.0	15.2	3.4	25.6	3.2	2.9	7.3	.52	3.7	0.0	.09	.20	0.0
Amphibolite[6]	47.4	21.3	8.5	11.0	1.7	3.9	3.9	.29	1.7	0.0	.11	.16	0.0
Amphibolite[6]	49.2	19.8	5.1	9.2	7.1	3.7	5.4	.27	.09	0.0	.09	.14	0.0
Marble[3]	38.0	1.8	.06	.09	30.2	.11	20.9	.04	.01	0.0	.02	.02	8.9
Horneblende Gneiss[7]	44.2	25.7	.64	4.1	14.3	.12	10.1	.27	.04	0.1	0.0	.4	0.0
Muscovite Quartz Gneiss[7]	49.6	36.1	6.6	.55	.38	2.0	0.0	4.7	.01	.01	.01	.01	0.0
Mangerite[7]	46.6	27.8	8.3	6.7	1.6	4.1	.12	4.1	.45	.07	.04	.16	0.0
Gabbro[7]	43.9	21.1	7.9	12.2	2.9	5.2	2.9	1.2	2.0	.04	.48	.18	0.0
Marble[7]	47.5	7.1	1.4	1.2	31.8	.24	2.0	.14	.06	0.0	.01	.05	8.59

1 Red Chalk Lake
2 Walker Lake
3 Duck Inlet #1
4 Dickie Lake
5 Paint Lake
6 Harp Lake
7 Rock Types identified and sampled within the Leslie M. Frost Center, Dorset. Calculated from data supplied by Mr. J.P. Trussler and Mr. R. Kievel

ELA bedrock (Brunskill et al. 1971) and average continental crust, granite, and shale (Krauskopf 1967) are given in Table 4 for comparison. Both major and some minor element concentrations are presented.

The biotite and horneblende granite gneiss (Table 3) are quartz and feldspar rich rocks whose bedding planes are emphasized by the uniform crystal orientation of biotite and horneblende and mineral segregation into distinct bands. The gneisses are similar in composition to the average granite composition given in Table 4 although Fe is slightly lower and K elevated in the Lakeshore Capacity Study samples. This compositional similarity may simply reflect the chemical composition of the sedimentary source material or the emplacement of a felsic igneous component during metamorphism. The horneblende gneiss represents the metamorphic equivalents of calcareous sand and silt-stone.

The meta-arkose rock has a chemical composition slightly elevated in Al and Fe relative to the "granite" gneiss and approaches the "average" granite composition of Table 4.

The muscovite quartz gneiss is a rock of very limited occurrence within the study area and roughly corresponds in composition to the acid intrusives commonly observed throughout Muskoka-Haliburton, although their origins are completely different (i.e., metamorphic and igneous). The rock is geologically considered "acidic" being principally composed of muscovite, quartz and feldspar. It is of interest to note that rock of this approximate composition dominates the Experimental Lakes Area. Brunskill et al. (1971) report that the bedrock at ELA is part of a massive granodiorite (hence igneous) batholith. In contrast, this rock which is remarkedly low in both calcium and magnesium relative to the other rock types as well as "average Canadian Shield" and "average granite" is of minor significance here.

Table 4: Chemical composition (O-K, 10^4 ppm; Ti-Ag, ppm) of average "Canadian Shield" rock, ELA bedrock, average "Continental Crust" rock, average granite, and average shale

Element	Average[1] Canadian Shield	ELA[3] Bedrock	Average[2] Continental Crust	Average[2] Granite	Average[2] Shale
O	47.9	49.3	46.4	49.0	55.9
Si	30.5	33.7	28.2	32.3	23.8
Al	7.8	8.35	8.2	7.7	8.0
Fe	3.1	0.80	5.6	2.7	4.7
Ca	2.9	0.98	4.1	1.6	2.5
Na	2.6	3.6	2.4	2.8	0.66
Mg	1.3	0.30	2.3	0.16	1.34
K	2.6	2.6	2.1	3.3	2.3
Ti	3,100	1,100	5,700	2,300	4,500
H	1,000		1,400		
P	700	500	1,050	700	770
Mn	500	200	950	400	850
S	600	30	260	270	220
C	3,500		200	300	1,000
Cr	99		100	4	100
Ni	23	20	75	0.5	95
Zn		50	70	40	80
Cu	14		55	10	57
Co	21	130	25	1	20
Li	22	230	20	30	60
Pb			12.5	20	20
Be	1.3		2.8	5	3
As			1.8	1.5	6.6
Mo			1.5	2.0	2.0
Cd			0.2	0.2	0.3
Bi			0.17	0.18	0.01
Hg			0.08	0.08	0.4
Ag			0.05	0.04	0.1

[1] Calculated from data taken from Shaw et al. (1967)
[2] From Krauskopf (1967)
- major element concentration (i.e., O through C) calculated from wt.%
[3] From Brunskill et al. (1971)

The marble bedrock (Table 3) is characterized by high calcium and carbon values since it is a metamorphic equivalent of limestone or dolomite. In an area dominated by silicate bedrock, the marble is an example of the relatively rare occurrence of Precambrian carbonate deposits which have survived the extended period of Phanerozoic erosion. The low Mg concentration for the marble collected on the Frost Centre property indicates that limestone was the probable parent rock. However, the marble analysis for the sample from Duck Inlet watershed represents the wide (>10m) continuous white beds common in the south-eastern sector of the study area. This rock is comparatively enriched in Mg with Si and Al concentrations being very low, indicating that a relatively pure dolomite was the source rock.

The chemical composition of two samples of amphibolite from Harp Lake watershed are given in Table 3. Iron and Mg are elevated and Si and K are depleted relative to the "average" granite composition given in Table 4. The meta-sedimentary amphibolite and igneous gabbro have approximately similar compositions. There is a very limited occurrence of gabbro within the study area.

The name "Mangerite" has been applied to some of the Frost Centre rocks. This rock is of intermediate composition and closely resembles diorite. The mangerite composition given in Table 3 is slightly depleted in Ca and Mg and enriched in Na and K relative to diorite. It should be noted that the silicon content of the diorites in the study area is unusually high thereby resulting in reference to them as "quartz diorites" or "tonalites". Both iron and aluminum are significantly higher in diorite than in the other metamorphic rocks of the area, a fact that is reflected in the relatively higher proportions of feldspar, amphibole, pyroxene and mica minerals in the igneous rock. The quartz containing diorite is found throughout the study area as large plutonic intrusions or small "plugs" intruding metasedimentary gneiss. As shown in Table 3 the

diorite is intermediate in Si, Fe, and Mg content, being elevated relative to the "granite" gneisses and depleted relative to the gabbros and amphibolites. The higher proportions of feldspar, amphibole, pyroxene and mica minerals in the diorite account for the elevated Fe, Mg and Al values.

Migmitite composition (Table 3) shows a range from "average granite" to slightly less mafic than diorite, e.g., Mg and Fe values are similar to those of granite gneiss while Fe and Ca values are slightly less than that of diorite.

Trace element analyses were not presented in Table 3 although some data is available for the Frost Centre samples. Trace element concentrations are remarkedly low in all cases; a fact which is supported by the failure to detect significant concentrations of sulphur in the rocks, and the paucity of economic ore deposits in Muskoka-Haliburton.

On a regional scale, the predominating bedrock minerals are quartz, feldspars, biotite and horneblende. All these minerals are silicates, extremely resistent to weathering, and incapable of providing much buffering capacity to surface water systems, hence the extremely soft, unproductive nature of most lakes in the area. Deep groundwater systems which are generally controlled by flow along cracks, fissures, and fault lines are of little significance compared to the major surface water systems.

2. Surficial Geology

The surficial deposits which occur in Muskoka-Haliburton are generally composed of unconsolidated material laid down during Quaternary glaciations plus more recent stream and beach deposits. All of these have been altered somewhat by weathering and soil forming processes in the intervening (geologically short) time period. The glacial deposits are of three principal types. First, reasonably uniform (in thickness) sheets of till were deposited

directly by the ice and are often referred to as "basal tills". Second, fluvial sand and gravel deposits of variable thickness and extent were deposited by meltwaters running off the glaciers and third, lacustrine deposits laid down in the several glacial lakes that developed and receded during the glacial withdrawal and subsequent readjustment (rebound) of the crust. Lacustrine deposits include both deep water (clay predominant) and clean beach sand types. At present, of course, deposition is occurring in lake basins, along current stream courses and in depressions (peat and muck) scoured out by the glaciers. Chapman (1975) gives the most complete general description of the surficial geology in the area. Nevertheless, as noted by Chapman himself, the scale of his efforts precluded mapping and discussion of all but the major surficial deposits hence providing incomplete information with regard to the watersheds of the specific study lakes. The following discussion of the regional surficial geology must be considered in light of specific information provided for the study lakes in a subsequent section.

2a. Glacial Deposit Types and Characteristics

Chapman has identified virtually all common types of glacial deposits within the Georgian Bay - Ottawa Valley area. Although not all of these are found within the area of particular interest to the Lakeshore Capacity Study (i.e., Muskoka-Haliburton) they have been included in the following discussion for completeness.

1) Till Plains

Till deposited directly by the glacier or as a blanket of material during the steady recession of the ice covers the greater part of Muskoka-Haliburton. The till cover is sometimes known as "ground moraine". It can range in thickness from a few centimetres to many metres but is characteristically very shallow and associated with numerous exposures of bedrock knobs and ridges. The till

is composed of a mixture of sand and rounded cobbles and bolders usually of granitic composition. It generally follows the contours of the bedrock. Chapman distinguishes two types of till based on deposit thickness and the amount of exposed bedrock. Our investigation has further subdivided the type of till, and their relationship to those of Chapman, and will be discussed in a subsequent section.

2) Drumlins

Drumlins are asymetrical oval-shaped hills formed under the glacial ice by mechanisms which are not yet understood. They are usually composed of till-like material but with a higher proportion of clay. Their elongate shape may be used to infer the direction of ice movement, i.e., in the direction of the long axis of the oval and towards the narrowest end. Very commonly they occur in swarms, perhaps in response to a higher proportion of clay in the material beneath the glacier. Given the low amount of clay present in most surficial deposits in Muskoka-Haliburton, it is therefore not surprising that few drumlins are present in the Lakeshore Capacity Study area. Chapman does note the presence of a swarm associated with a spillway network in Snowdon, Minden, and Dysart Townships and few in Draper Township near Bracebridge, but these occurrences are minor on a regional scale.

3) Moraines

There are several types of moraines, each type being an accumulation of debris that has collected at the edge of the glacier. If the glacier is at equilibrium, i.e., rate of advance just equalling the rate of melting, then a large mound of material can accumulate which is later observed as a more or less uniform ridge that often extends for long distances. Although such deposits are very common in most

glaciated areas, the Muskoka-Haliburton area has noteably few of them either because consistent ice movement resulted only in the deposition of till plains or because such structures were reworked (and hence destroyed) by the several different drainage systems that developed and disappeared as the ice receded and the crust rebounded.

4) Eskers and Kames

These glacio-fluvial deposits are accumulations of sand and gravel (often existing in poorly developed strata) formed from the finer debris carried off the glaciers by meltwaters. Specifically, eskers are the deposits laid down in the stream bed located on top of or within the glacier and on eventual glacial recession are left as long sinusoidal ridges. Kames form where streams empty into temporary glacial lakes formed by ice damming. The widely fluctuating levels in these lakes result in kame deposits being mixtures of fluvial and till material, in essence intermediate between moraines and eskers. The well sorted, coarse-grained nature of these deposits often makes them economically useful as a supply of road gravel. Few large deposits are found in Muskoka-Haliburton although several have been identified to the north and east (in Algonquin Park) where they are associated with major spillway systems and drumlins in some cases.

5) Spillways

Meltwater streams carrying material beyond the glacier's face deposited their suspended sediment load in the many spillway systems or outwash terraces found in the area. As expected, the material in the spillways is finer and more uniform than that found in esker deposits, i.e., silt and sand, although some gravel may be found. In many cases distinct bedding and ripple marks have been preserved. A common feature is the presence of large depressions in the

spillway material, these being caused by the melting of large ice-blocks which probably formed as ice lenses during deposition of the spillway. Because of the flat well-drained nature of spillways, roads are very commonly built on these deposits. In the Lakeshore Capacity Study area, major spillways are located along Highway 503 and 519 in Haliburton, along the Gull River near Minden and along Highway 60 to the northeast of the Lake of Bays. Numerous other occurrences have been identified by Chapman and ourselves (see following sections). Both the esker and spillway deposits are often dissected by present stream systems.

6) Lake Plains - Beach sands and clay deposits

As the Wisconsin Glacier receded, Lake Algonquin formed in the Lake Michigan, Lake Huron and Georgian Bay basins. Beach sand (clean, well sorted) and clay deposits (in deep water) were formed in this lake and are primarily found along the Highway 11 corridor from Orillia to North Bay. They are commonly stratified clay, silt, and sand with the latter on top. The clay and silt have regular alternate darker and lighter layers - "varving" typical of deposition in glacial lakes.

2b. Soils

(i) Soil Formation and Classification

Classically, the origin of soils is viewed in light of rock weathering processes. Bedrock type and climate are the principal controlling factors determining the soil type formed. Attack of the bedrock by the atmosphere and precipitation results in partial dissolution, physical break-up, and downward movement of dissolved material and colloidal particles. Vegetation and bacteria are important in catalyzing this process, and the resulting soil may be

simply considered as one of the last stages of the weathering process. This view must be altered somewhat for Muskoka-Haliburton soils where the soil material is not the product of simple in place weathering, but is the result of glacial transport reflecting a variety of depositional environments. This fact may result in differing watershed responses to the input of nutrients, acid precipitation or any other environmental stress. The degree of weathering will depend on the type of material, geomorphology of the area, and the climate (which may be considered constant over the study area).

The essential feature of classical soil formation and maturation is the downward transport of materials from one level to another resulting in zones or horizons with characteristic compositions. Horizons are usually designated by letter, with "A" being the uppermost and corresponding to the layer from which downward moving water has removed much of the soluble material. "B" is the intermediate layer in which some of the soluble and colloidal material is deposited, and "C" is the zone of fragmented but still largely unaltered debris that grades down into bedrock. Further, inter-horizon subdivisions are common.

The above processes must be considered in light of the following characteristics of the unconsolidated parent material present in Muskoka-Haliburton:

1) a large proportion of the surficial deposits are composed of sand and silt (SiO_2) and gravel of granitic composition. This material is very resistant to weathering and very poor in leachable or exchangeable bases (i.e., cations).

2) Soils in the study area contain remarkedly low quantities of silt and clay size particles. The

relatively large particle sizes minimize contact with percolating solutions thereby also reducing the degree of weathering that occurs. Both of these features are manifested in the dilute nature of the stream systems in the area.

3) Clay found in the area usually occurs as pure, impermeable deposits, and although they possess a much higher potential for cation exchange, this is minimized by the ineffectiveness of water percolation.

4) The shallowness of most of the surficial material is of major importance.

These critical factors coupled with the inherent resistivity of the granitic bedrock to weathering, the geologically short period of time since the last glaciation, the temperate climate, and forest type has resulted in acidic soils with poor or absent profile development. A common soil type developed under these conditions is called a Podzol. The surface layer of the Podzol is composed of partially decomposed leaf litter underlain by a white-grey highly leached Ae horizon. The subsequent removal of Fe compounds from the Ae horizon and deposition in the 'B' horizon give the 'B' horizon its characteristic reddish hue. Podzolic development is most complete on the well drained, coniferous tree dominated ridges covered by a thin veneer of till. Discontinuous podzolic soil development often results from tree uprooting causing soil profile disruption in these thin overburden areas.

In poorly drained areas which are water saturated for part of the year, the surface litter and decomposing organic layer is thicker. The Ae horizon in these poorly drained areas is weakly defined or absent and the 'B' horizon is a dark brown instead of the reddish brown associated with

Podzolic soils. The 'B' horizon is weakly defined and is dominated by sand and gravel size materials rather than silt and clay size particles. Such poorly developed soils are intermediate in character between true Podzols and other soil types, principally Brunisols and Gleysols.

Brunisolic soils are classically considered to form under Tundra like vegetation and unlike Podzols lack a highly leached Ae horizon and a significant accumulation of clay and organics in the 'B' horizon. Within the Lakeshore Capacity Study area soils formed on well drained coarse grained parent material may exhibit a poorly defined Ae and B horizons. Hence, many of the soils in the study area may be considered Brunisols.

Gleysolic soils form in areas saturated with water for at least part of the year. A typical gleysolic profile contains a mottled Ae horizon, clay accumulation in the 'B' horizon. The 'C' horizon often shows accumulation of carbonate material. Soil of the gleysolic type is restricted to the south-east section of the study area, where Precambrian marble beds and relatively carbonate rich till are common. The marble beds are often found in the center of poorly drained valleys.

Organic soils (peat) form in areas saturated with water for a large part of the year. The organic material is supplied by the growth of grasses, reeds, rushes, sedges, mosses and trees. Organic accumulations are common in most poorly drained areas. The organic deposits may:

1) occur as large extensions of lake bays usually overlying a sand deposit,

2) occupy depressions in glacial fluvial deposits, or

3) occupy perched bedrock pockets.

Distinct soil horizons are rare and a gradual increase in density and decrease in particle size is found with increasing depth. The organic soil have a high water retention ability although downward percolation of water is very limited.

In summary, the dominant soil types of the study area are acidic Brunisols and Podzols. The brunisolic and podzolic soils form on non-carbonate, moderate to well drained slopes generally on coarse grained parent surficial material. Gleysolic soil development is limited to moderately to poorly drained valleys in the south east corner of the study area underlain by marble. Organic soils are common throughout the study region in zones of very poor drainage.

(ii) Soil Geochemistry

The mean elemental composition of soil horizons and bedrock types found in the study area are given in Table 5 and 6 respectively.

The mean elemental composition of the soil horizons given in Table 5 compares favourably with the elemental composition of migmitite bedrock given in Table 6. Since regional bedrock composition is dominated by granite gneiss and migmitite and to a much lesser extent by diorite or equivalents, the felsic nature of the surficial material is as expected. Gabbro and amphibolite bedrock are localized in occurrence but dispersal of the mafic material may result in zones of elevated Fe and Mg in the surficial material. The paucity of carbonate bedrock to the north and in the study area itself with the exception of the south east corner is reflected in the very low Total Inorganic Carbon (TIC) values presented in Table 5. The deeper, relatively unweathered 'C' horizon has Ti, Mn and P values similar to the migmitite bedrock and somewhat lower than the gabbro and amphibolite bedrock values given in Table 6.

Table 5: Mean composition (%) of the soil horizons found in the study area. Soil horizons considered have been restricted to those developed on glacial till, spillways, or raised beach deposits

	ELEMENT												
Horizon	O	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	P	S	TOC	TIC
A	44.3	32.1	5.30	2.45	.40	1.38	1.60	1.86	.40	.09	.01	.09	20.83	.27
Ae	46.6	32.9	6.10	2.82	.59	1.67	1.90	2.21	.57	.07	.01	.02	9.1	1.27
B	43.8	28.4	6.99	4.99	.86	2.19	1.80	1.95	.51	.09	.06	.05	17.0	.43
C	46.0	30.6	7.36	3.77	1.06	2.38	2.03	2.04	.50	.10	.06	.01	1.0	.36

The number of samples in given mean composition of elements O, Si, Al, Fe, Mg, Ca, Na, K, Ti, Mn, P for A, Ae, B, C soil horizon is 1, 5, 10, 6 respectively.

The number of samples in given mean composition of elements S for A, Ae, B, C soil horizon is 4, 3, 5, 2 respectively.

The number of samples in given mean composition of elements TOC and TIC for A, Ae, B, C soil horizon is 5, 3, 4, 2 respectively.

Element analysis of O, S, Al, Fe, Mg, Ca, Na, K, Ti, Mn, P were completed on one set of samples while S and TOC, TIC values are from separate sample sets.

Table 6: Mean composition (%) of the major bedrock types found in study area. Due to the wide diversity of marble composition, composition of 2 marble types has been included.

	ELEMENT												
Horizon	O	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	P	S	C
Granitic Gneiss	48.7	34.3	7.05	1.60	.51	1.10	2.15	4.40	0.16	0.04	0.03	ND	ND
Migmitite	50.7	29.7	5.56	4.33	.96	2.00	2.03	4.27	0.43	0.10	.06	ND	ND
Diorite	46.4	27.4	7.9	7.9	1.9	4.9	2.5	0.60	0.38	0.12	.03	ND	ND
Gabbro	48.0	17.9	4.5	11.9	5.4	4.4	3.1	1.23	2.97	0.18	.39	ND	ND
Amphibolite	48.2	20.6	6.8	10.1	4.7	4.4	3.8	0.28	0.86	0.15	.10	ND	ND
Marble	38.0	1.8	0.06	0.09	20.9	30.2	0.11	0.04	0.01	0.02	.02	ND	8.90
Marble	47.5	7.1	1.4	1.2	2.0	31.8	0.24	0.14	0.45	0.16	.06	ND	8.59

The number of samples represented by the mean composition of granitic gneiss, migmitite, diorite, gabbro, amphibolite and marble elemental composition composition is 2, 3, 1, 4, 2, 1, 1 respectively.

ND - below detection limit of $\simeq$.02%

The varying physical and chemical properties of study area soils have been influenced by site specific factors including the nature of the parent material, drainage, and vegetation type. However, with the exception of peat accumulations, the soils share many similar physical and chemical characteristics and these are summarized in Table 7. The mean thickness of the A, Ae, and B horizons are 12, 9, and 40 cm respectively. The 'C' horizon maximum depth was only established in a few till sections and in many cases did not exist at all at the sampling site due to the overall thinness of the overburden. (Methods adapted for physical and chemical analysis were based on Black (1965)). The sand size fraction dominates in all horizons reaching a maximum in the 'C' horizon (mean = 88%) and a minimum in the 'B' horizon (mean = 68%). The mean silt content is a maximum in the 'B' horizon (mean = 29%) as a result of transport from the Ae horizon (mean = 18%). The clay content of the soils is extremely low. Both the mean and range of the percent clay size fraction decreases with depth from a maximum in the A horizon (7%) to a minimum in the relatively unweathered 'C' horizon (2%).

The organic matter content of the mineral soils is reflected in the loss on ignition (LOI) data. Loss on ignition exhibits a typical "podzolic" profile with an 'A' horizon maximum (mean = 32%) and a reduced value in the 'Ae' horizon (3%). Accumulation of organic decay residues in the 'B' horizon gives a mean of 8% while the lower 'C' horizon contains virtually no organic matter (mean = 1%).

Consideration of the cation exchange capacity (CEC in meq $100g^{-1}$) given Table 7 along with the corresponding LOI data suggest that the organic component of the soil may be the most important contributor to the CEC in these coarse grained silicate soils.

Table 7: Summary of selected physical and chemical parameters for horizons developed in mineral soils in the study area.

Soil Horizon		Horizon Upper Limit (cm)	Horizon Lower Limit (cm)	Sand %	Silt %	Clay %	L.O.I. %	CEC meq/100g	pH (H_2O)	pH (.01$CaCl_2$)	TEB meq/100g	% Base Sat.
A	$\overline{X}$	0	12	72	21	7	32	61.1	4.1	3.7	3.4	6.8
	min.	0	5	56	6	1	9	24.0	3.7	3.2	.4	1.2
	max.	0	25	89	39	17	78	146.7	5.3	4.2	8.1	18.3
	(n)	(11)	(11)	(9)	(9)	(9)	(11)	(11)	(11)	(11)	(11)	(11)
Ae	$\overline{X}$	8	17	77	18	5	3	15.4	4.1	3.6	.7	4.6
	min.	5	8	68	12	2	3	12.0	3.7	3.2	.2	1.1
	max.	15	25	86	27	10	4	17.8	4.4	4.3	1.2	10.0
	(n)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)
B	$\overline{X}$	15	55	68	29	3	8	30.6	4.5	4.2	.5	2.4
	min.	10	30	36	17	0	1	9.0	3.4	3.3	.3	.5
	max.	25	69	84	61	7	19	74.6	5.0	4.7	1.1	4.8
	(n)	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)
C	$\overline{X}$	44	-	88	10	2	1	10.1	5.2	4.7	.4	4.7
	min.	30	-	69	1	1	0	5.1	4.8	4.6	.1	.4
	max.	51	-	98	28	4	4	14.9	5.5	4.9	.8	6.7
	(n)	(6)	-	(7)	(7)	(7)	(7)	(10)	(10)	(10)	(10)	(10)

LOI = loss on ignition

CEC = cation exchangeable capacity

TEB = total exchangeable bases

The mean value for total exchangeable bases (TEB in meq $100g^{-1}$) is a maximum of 3.4 for the "A" horizon and is < 1 for all lower horizons. Maximum percent base saturation therefore also occurs in the A horizon (6.8%) with the 'Ae', 'B', and 'C' horizons having values of 4.6, 2.4, and 4.7 respectively. The quantity of exchangeable bases in the Lakeshore Capacity Study soils is very low.

The mean exchangeable Ca, Mg, Na, K, Al and P adsorption data is summarized in Table 8. The exchangeable Ca, Mg, Na and K are highest in the surface 'A' layer and become increasingly depleted with depth. Calcium dominates the exchangeable bases in all soil horizons while Na is minimum in all cases.

A small number of exchangeable Al analyses were performed with the maximum mean value (3.15 mg $100g^{-1}$) occurring in the 'B' horizon as expected. Aluminium is clearly the dominant exchangeable species in this horizon. The next highest exchangeable Al content is found in the 'A' horizon which simply reflects the overall maximum CEC occurring at this level (Table 7).

The mean P adsorption data (also for a limited number of samples) is given in Table 8. The maximum mean phosphorus adsorption (28.7 mg $100g^{-1}$) predictably occurs in the 'B' horizon where Fe and Al oxide levels are also maximum. The high CEC values found in the 'A' horizon also contribute to the relatively high maximum P adsorption levels found in this horizon. The P adsorption is low (mean 5.8 mg $100g^{-1}$) in the 'C' horizon as expected. Two previous studies on Precambrian Shield soils (Aitkens 1975, Ministry of Environment 1977) also found 'B' horizons to have the highest phosphorus adsorption usually greater than 20 mg $100g^{-1}$. The 'C' horizons exhibited phosphorus adsorption values which were usually less than 10 mg $100g^{-1}$ and in some cases negligible. In summary, the 'A' and 'B'

Table 8: Summary of exchangeable Ca, Mg, Na, K (meq 100g-1), Al (mg 100g-1) and P absorption (mg 100g-1) for horizons developed in mineral soils in the study area.

Soil Horizon		Ca meq/100g	Na meq/100g	K meq/100g	Mg meq/100g	Al mg/100g	P Adsorption mg/100g
A	$\overline{X}$	2.06	.05	.55	.71	1.84	26.8
	min.	.26	.01	.06	.01	.65	4.8
	max.	6.6	.12	1.32	2.22	4.8	48.8
	(n)	(11)	(11)	(11)	(11)	(4)	(2)
Ae	$\overline{X}$	.44	.02	.06	.13	.46	-
	min.	.11	.02	.05	.03	.26	-
	max.	.78	.03	.07	.37	.86	-
	(n)	(6)	(6)	(6)	(6)	(3)	
B	$\overline{X}$	.38	.02	.05	.06	3.15	28.7
	min.	.14	0	.02	.01	1.89	1.9
	max.	.94	.04	.13	.18	5.20	56.1
	(n)	(11)	(11)	(11)	(11)	(4)	(5)
C	$\overline{X}$	.06	.02	.02	.06	.60	5.8
	min.	.01	.01	.01	.01	.43	0
	max.	.36	.03	.03	.36	.73	12.3
	(n)					(1)	(4)

soil horizons exhibit moderate phosphorus retention while the 'C' horizon being coarse in particle size, low in organic and Fe, Al oxides shows low to negligible phosphorus adsorption.

A comparison of pH and cation exchange capacity (CEC) of soils in the study area and at Hubbard Brook, New Hampshire is presented in Table 9. Both the Lakeshore Capacity Study and Hubbard Brook soil profiles have developed on silicate bedrock and show increasing pH with depth. Considering the 'A' horizon, they exhibit great variability in CEC, with the Hubbard Brook data falling within the range of these data. The higher CEC values in the 'A' horizon of Muskoka-Haliburton soils may be attributed to exchange sites created by organic decay residue since the quantity of clay and silt size particles in this horizon is only marginally elevated. The 'Ae' horizon shows little difference in pH compared to the 'A' horizon although the CEC is considerably lower. The limited organic material remaining in the 'Ae' horizon and the mineral component have been subject to intense weathering since glacial retreat. The paucity of cation exchange sites in this horizon may be attributed to downward transport of organic decay residues, other weathering products and fine mineral particles derived from the coarse grained parent material.

The 'B' horizon samples generally show a wider and lower range in pH values than those from Hubbard Brook while they have a range in CEC encompassing that given for Hubbard Brook. In both cases, 'B' horizon CEC values are higher than the corresponding Ae values and lower than those given for the 'A' horizons. Iron and Al oxides dissolved from the Ae layer and re-deposited in the 'B' horizon may account for this observation.

The CEC is generally lowest in the 'C' horizons for both the Lakeshore Capacity Study and Hubbard Brook soils and

Table 9: Range of pH[1] and cation exchange capacity (CEC in meq/100g) for soil horizons in the study area and at Hubbard Brook, New Hampshire[2].

		Lakeshore Capacity Study	Hubbard Brook[2]
A	pH	3.2 - 4.2	3.2 - 4.5
	CEC	24 - 147	97 - 118
Ae	pH	3.2 - 4.3	3.7 - 4.8
	CEC	12 - 18	6
B	pH	3.3 - 4.7	4.0 - 5.1
	CEC	9 - 75	13 - 47
C	pH	4.6 - 4.9	5.0 - 6.0
	CEC	5 - 15	3 - 5

1 Soil pH measured with .01 M $CaCl_2$ (soil:solute = 1:2)

2 Johnson, M. et al., (1981)

may be attributed to paucity of organic material, absence of Al and Fe oxides and coarse grained nature of the parent material. The pH of the 'C' horizon is higher than in the overlying horizons.

2c. Geology - Vegetation Relationships

The preference of certain species of vegetation for a given surficial deposit (and perhaps bedrock) type has been recognized. Although crude, these empirical relationships have been used to advantage for predicting watershed geology from airphotos prior to groundlevel mapping. In general, the following relationships have been used: (also summarized in Table 10).

1) Outwash sand (spillway deposits)
White pine and white birch are the most common tree types growing on these sand and gravel deposits, although many of them have been cleared for agricultural purposes and are therefore grass-covered.

2) Till deposits (including drumlins and moraines)
Mature hardwood forest is usually found on till deposits. Maple and beech are the predominant tree types although a few other hardwoods and an occasional pine may be found. The local stands of pine are usually associated with thin till and bedrock outcrops. Usually very little underbrush is found in these forests.

3) Lowlands containing peat and clay
Poor drainage from many lowland areas result in the presence of sphagnum bogs surrounded by stands of hemlock, balsam, and some spruce.

Table 10: Criteria for definition of surficial deposit types in the study area

Surficial Geology Map Unit	Air Photo Evidence	Field Criteria
Minor till	- light colour, smooth and continuous - minor faults not visible - gentle, sloping deposits on south side of rock knobs - vegetation: maple, beech, ironwood	- deposit > 1 meter thick, material unsorted - A, B and C horizons developed - till cover continuous - erratics present
Thin till and rock ridges	- mottled appearance due to conifer-deciduous patches - minor faults visible - associated with steeper slopes - vegetation: yellow birch, poplar, pine and hemlock	- deposit < 1 meter thick, material unsorted - A and B horizons developed, C horizon usually absent - rock ridges present - erratics present
Peat (various kinds)	- dark colour - level plain - "puffy" or "spiky" appearance due to conifers - vegetation: hemlock, balsam, black spruce, sphagnum	- highly organic soil lying over sand or clay or bedrock, occasionally over till - level, no rock ridges - no soil profile development - no erratics present - subsurface sand usually well sorted - peat usually thin when situated directly over bedrock, a few small erratics present in this case
Exposed Bedrock	- glare - jointing pattern visible - sparsely treed - vegetation: moss, pine	- exposed bedrock - some small pockets of thin till - bedrock weathered - a few large erratics present
Outwash plain	- dark colour near water but light colour elsewhere - level plain with some terraces - vegetation: maple, beech, white pine	- deposit > 2 meters thick - moderately sorted sands and gravel - A, B and C horizons developed - interbedding of sands and gravels - cross-bedding evident - no erratics present
Sand	- dark colour - level - raised above local water table - vegetation: white pine, brambles	- well sorted sand deposit - A, B and C horizons developed - deposits level - no erratics present

2d. Glacial Recession and Surficial Geology

The period of glacial recession following the Wisconsin glacial advance had a profound effect on the surficial geology of the study watersheds.

Glacial Lake Algonquin occupied a large portion of the study area during glacial recession. The north shore of the lake was formed by the receding Wisconsin ice sheet, while the land mass forming the south shoreline underwent isostatic rebound. Chapman (1975) places the upper limit of submergence in Bracebridge at 293 meters above present sea level, Dorset at 340 meters and Trout Creek at 365 meters. Chapman (1975) also notes a small annex of Lake Algonquin extended north-east of Balsam Lake and into the Gull River Valley. The influence of Lake Algonquin on a particular watershed was governed by the watershed elevation and the presence or absence of an external sediment source. Based on the above criterion the study lakes' watersheds may be separated into three groups.

The first group are those lake watersheds whose elevation placed them above the highest shoreline attained by Lake Algonquin. These watersheds include Chub, Solitaire, Little Clear, Buck, Walker, Basshaunt and Bigwind. The watersheds are typified by surficial till deposits and a relatively low percentage of peat bog. Although elevated above the glacial lake level, the watersheds Solitaire, Little Clear and to a lesser extent Basshaunt are intersected by regional faults which have acted as glacial meltwater spillways. The spillway deposits of Little Clear and Solitaire watersheds are an extension of a large sand and gravel spillway partially mapped by Chapman (1975) terminating at the northern tip of the Lake of Bays. The deposit is 75 meters deep and dominates the central basin area of Solitaire and Little Clear watersheds. The spillway deposits joining Basshaunt and Bushwolf lakes are confined to narrow valleys and less regional in extent than the Solitaire Little Clear spillway complex.

The second group include Crosson, Gullfeather, and Dickie which had major portions of their basins submerged in Lake Algonquin but had no external introduction of sediment. The dominant characteristics of these lake watersheds are expansive peat bogs overlying shallow sand deposits which are in turn surrounded by extensive areas of thin till and rock ridges. The erosion of the till veneer by a fluctuating Lake Algonquin shoreline, and subsequent migration of the finer sized material to the lower sections of the watersheds is apparent. The bedrock bound and hence poorly drained sand and silt lenses now host the large peat bogs found adjacent to Crosson, Gullfeather and Dickie Lake.

The watersheds of Harp, Jerry, Red Chalk and Blue Chalk were also partially submerged in Lake Algonquin but were in communication with sediment laden waters. The larger watersheds of Harp and Jerry were connected for at least short periods of time to the East River basin, a major route of sediment transport. A large sand delta - raised beach complex rising 10 meters above the north shoreline of Jerry Lake is a direct result of sediment influx from the north. Likewise the Harp drainage basin exhibits sand lenses adjoining the lake which are 15 meters in depth. The Red Chalk and Blue Chalk watersheds were joined to the Black River spillway route in the south and sediment laden St. Mary's Lake, Trading Bay and Lake Bays in the north. The major deposit is a level, cobbly outwash on the flanks of Red Chalk Lake with smaller ribbon deposits occurring on the Blue Chalk shoreline.

V. INDIVIDUAL WATERSHED DESCRIPTIONS

1. "A" Lakes

Bedrock and surficial geology mapping of the watersheds of Harp, Jerry, Dickie, Chub, Red Chalk and Blue Chalk Lakes (the "A" lakes) has been completed. The bedrock types identified in these basins include gneiss, diorite, amphibolite and schist, and migmitite,

while the surficial deposit types include minor till plain, thin till and rock ridges, peat (various kinds), exposed bedrock, outwash plain and sand.

Bedrock mapping was achieved by direct field observation of rock outcrops. Surficial geology mapping was performed by a two step process involving initial stereoscopic assessment of the lake basins using air photos followed by field verification. The criterion used for defining the surficial types were outlined in Table 10. Application of these techniques has allowed the preparation of maps with a far higher degree of resolution than is available in any other published reports.

The bedrock geology and basin designation of Red Chalk and Blue Chalk, Chub, Dickie, Harp and Jerry Lakes are given in Figures 2 through 6 respectively. Figures 7 through 11 give the corresponding surficial geology for these watersheds. Tables 11 and 12 present a summary of the results for the sub-watersheds and whole basin of each "A" lake, expressed as percent areal extent of the bedrock and surficial deposit types respectively. Also included under surficial deposit type are ponds which make up a significant percent of the sub-watershed in a few cases, particularly in the Red Chalk Lake basin. Sub-basin designations are as indicated in Figures 2 through 6.

Gneiss or migmitite (in the case of Dickie Lake) is found throughout the area. The predominance of this type suggests that a fairly uniform regional bedrock composition may be expected although the presence of horneblende at Dickie, Harp and Jerry Lakes shows slightly higher levels of calcium and perhaps iron and magnesium in these drainage basins. Only the Harp Lake basin (Fig. 5) exhibits any degree of complexity with significant exposure of amphibolite ($\simeq$28% of the total basin) in the west, and a small amount of intruded diorite ($\simeq$3%) in the east.

The drainage patterns exhibited in Figures 2 through 6 are typical of the area. The angular (non-dendritic) pattern is the result of

"structural control" with many of the streams following fractures and faults in the rock. Also, in the Harp Lake basin, portions of inlet streams #4 and #6 are seen to flow along the contact between the different rock types.

In contrast to the uniformity of the bedrock, the surficial geology is highly variable, with many of the glacial and recent types of deposits found in all the basins. The Dickie Lake basin has the least variable surficial geology, with thin till and peat predominating (overlaying layers of clay and sand) and a generally flat terrain. Thin till is also the major surficial unit in the Chub and Jerry Lake watersheds, although the occurrence of minor till here is more extensive than at Dickie Lake while peat is conversely less important. At Chub Lake, peat deposits generally lay directly on bedrock while at Jerry and Harp Lakes, the peat usually covers sand deposits of variable thickness.

Minor till plain is the major surficial deposit (on average) at Blue Chalk, Red Chalk and Harp Lakes although it should be noted that a great variability is found between the subwatersheds of the latter two basins. Among these subwatersheds are further examples where thin till is most important (Red Chalk #2, Harp #'s 5, 6 and 6A). As observed in the Dickie Lake basin, the most significant peat deposits are often associated with this thin till.

The poorly sorted outwash sands and gravels at Red Chalk and Blue Chalk Lakes, and the well sorted beach sands at Harp and Jerry Lakes are noteworthy.

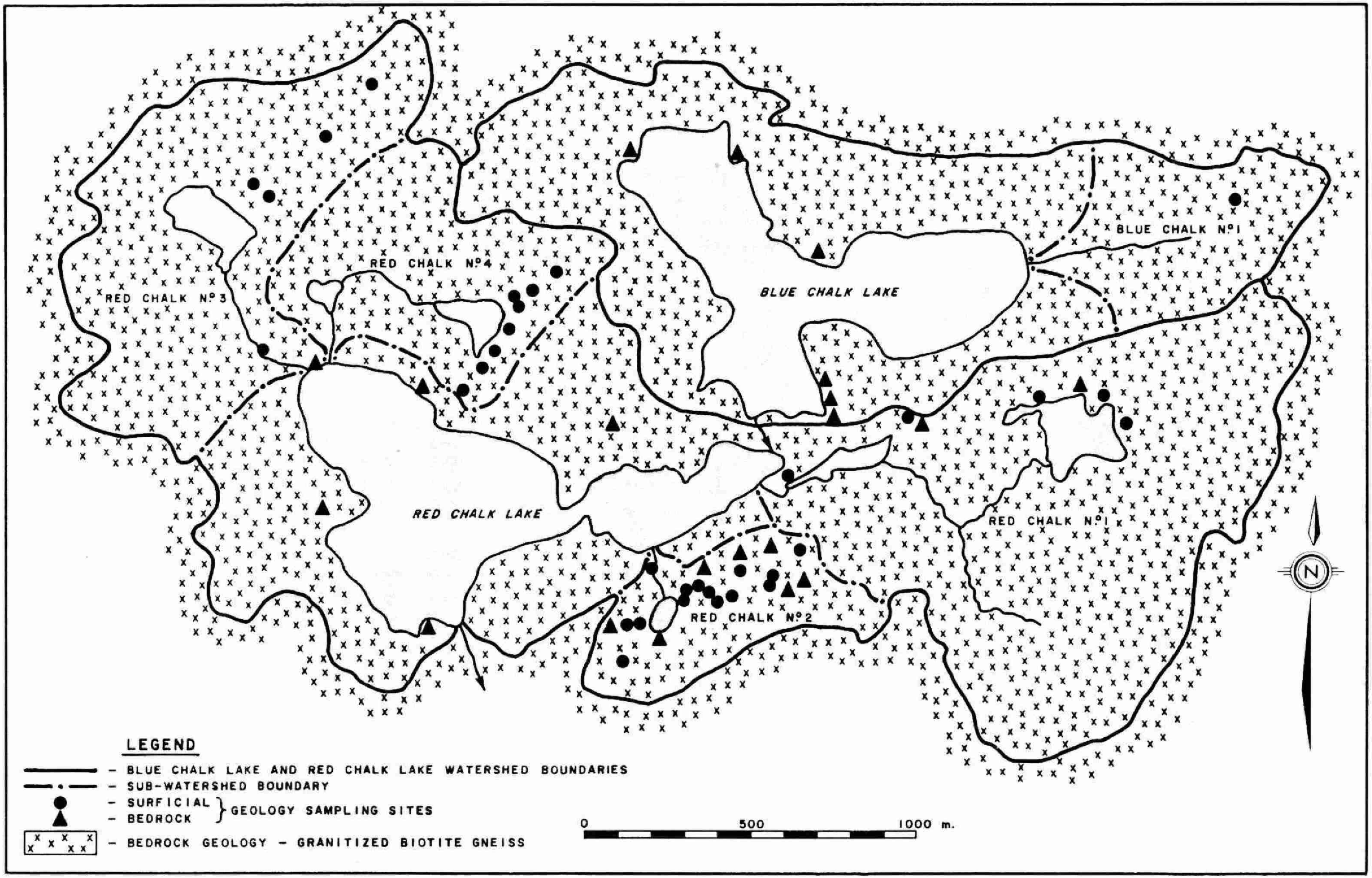

FIG. 2 - BEDROCK GEOLOGY, SAMPLING SITES, AND BASIN DESIGNATION OF THE BLUE CHALK AND RED CHALK LAKES WATERSHED.

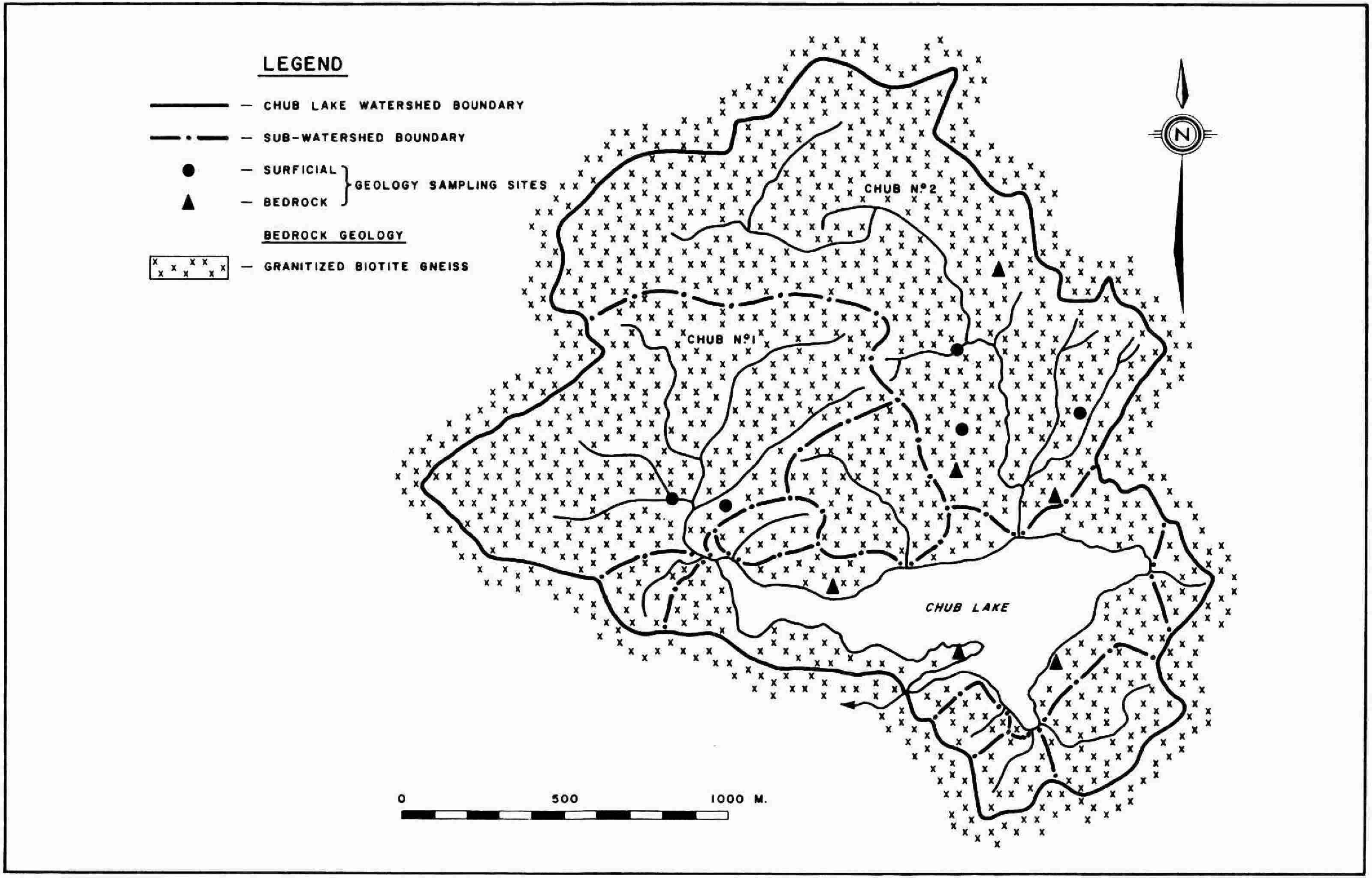

FIG. 3 BEDROCK GEOLOGY, SAMPLING SITES AND BASIN DESIGNATION OF THE CHUB LAKE WATERSHED.

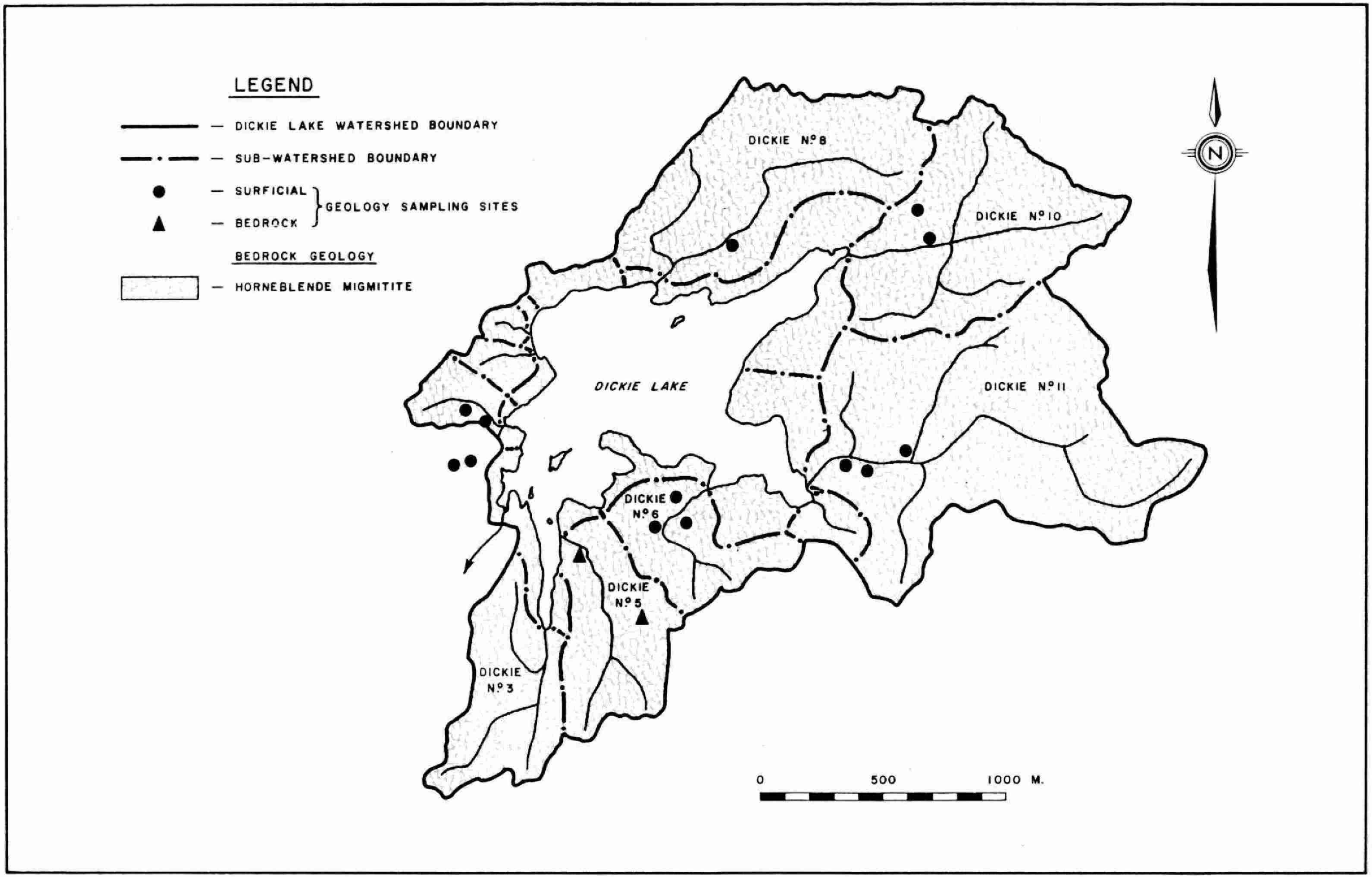

FIG. 4 BEDROCK GEOLOGY, SAMPLING SITES AND BASIN DESIGNATION OF THE DICKIE LAKE WATERSHED.

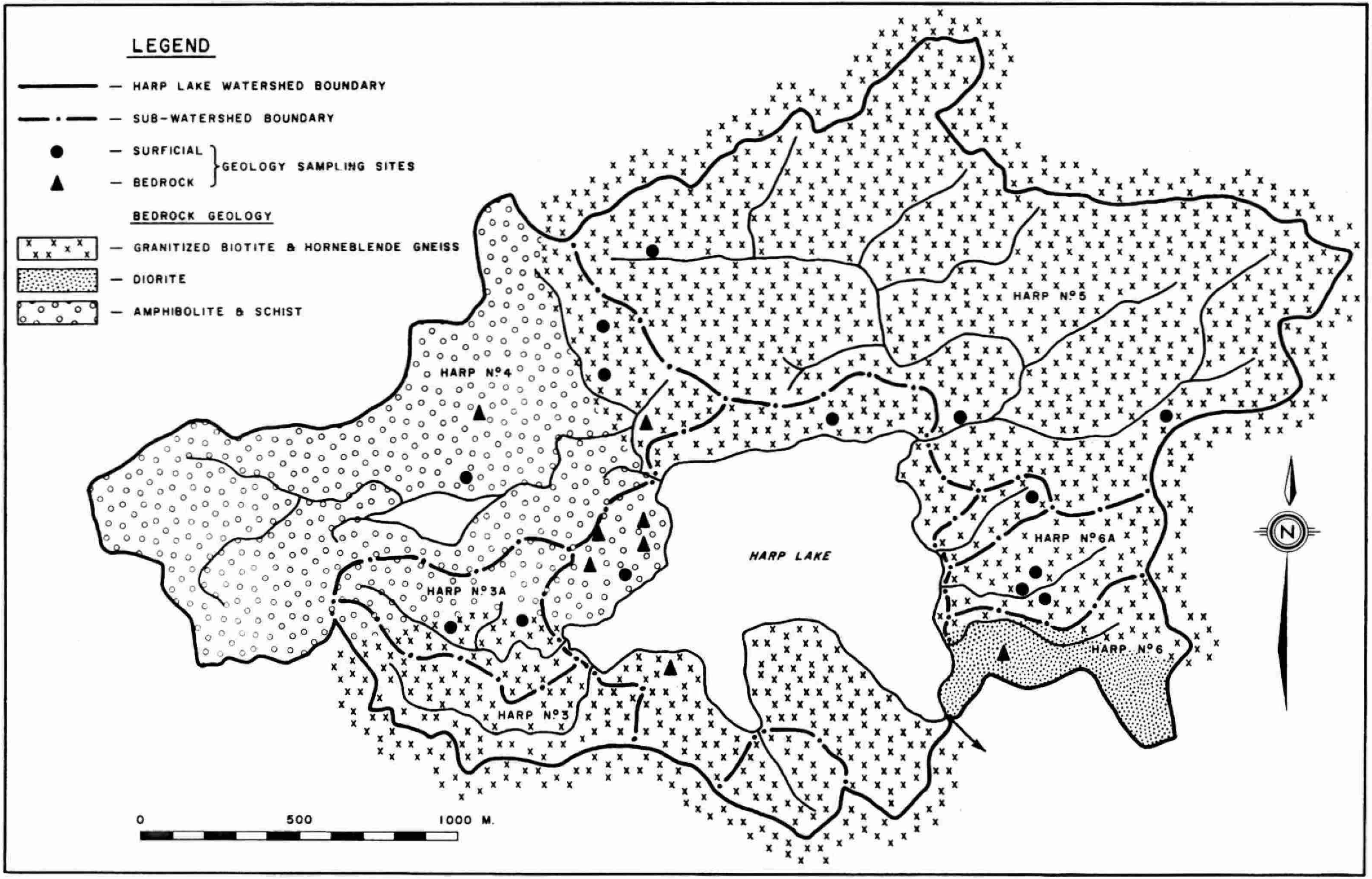

FIG. 5 BEDROCK GEOLOGY, SAMPLING SITES AND BASIN DESIGNATION OF THE HARP LAKE WATERSHED.

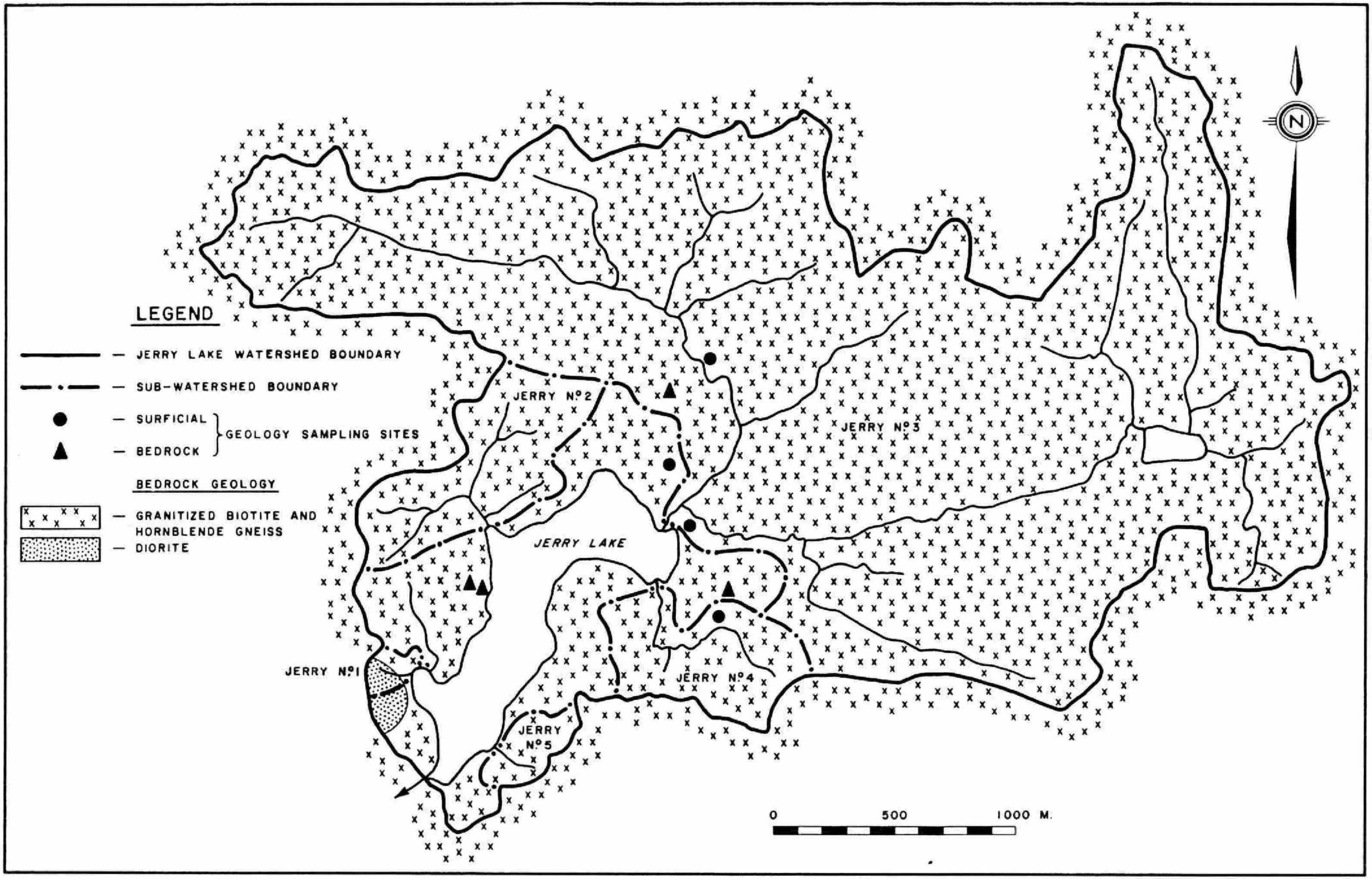

FIG. 6 BEDROCK GEOLOGY, SAMPLING SITES AND BASIN DESIGNATION OF THE JERRY LAKE WATERSHED.

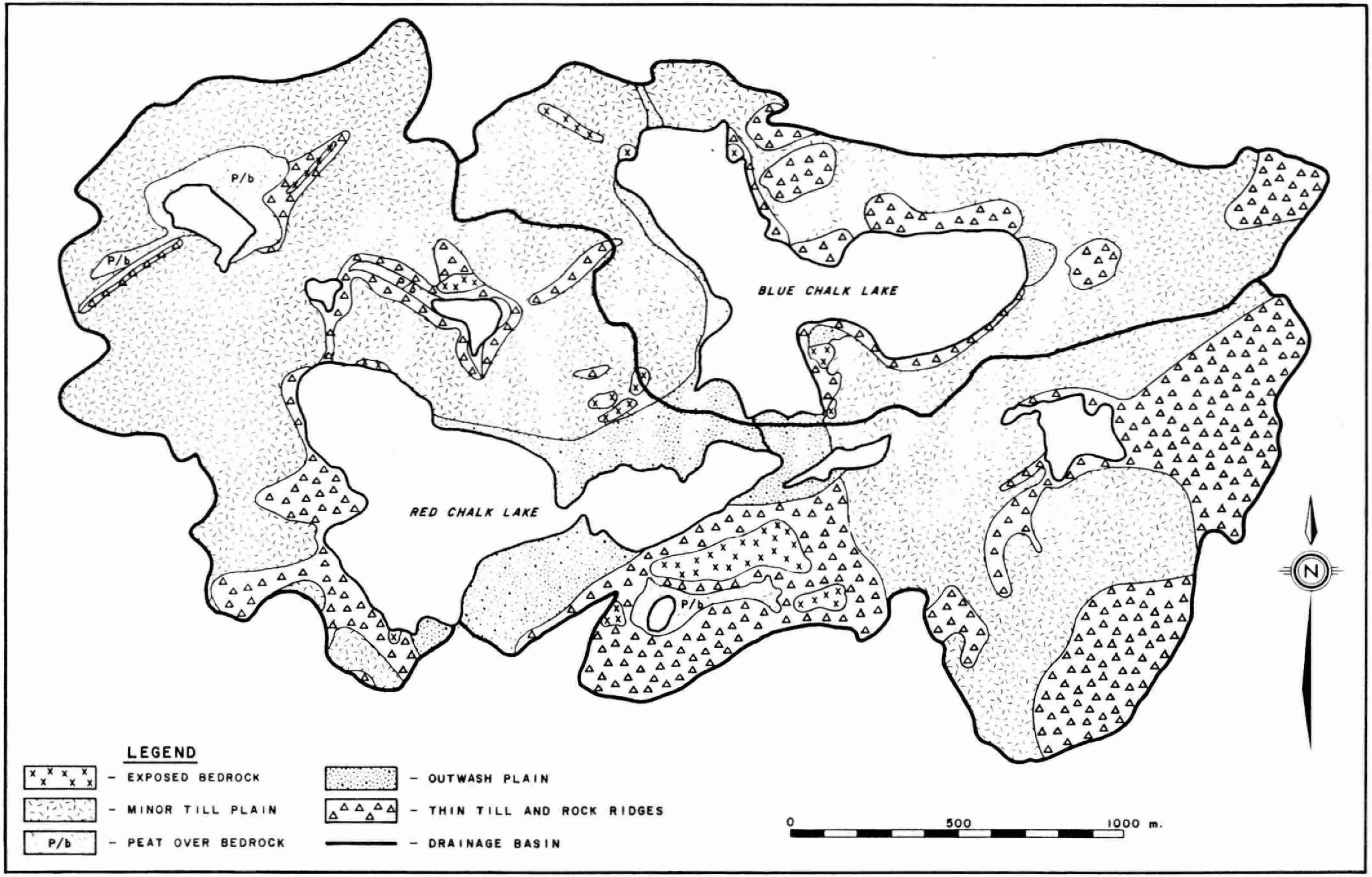

FIG. 7 - SURFICIAL GEOLOGY OF THE BLUE CHALK AND RED CHALK LAKES WATERSHED.

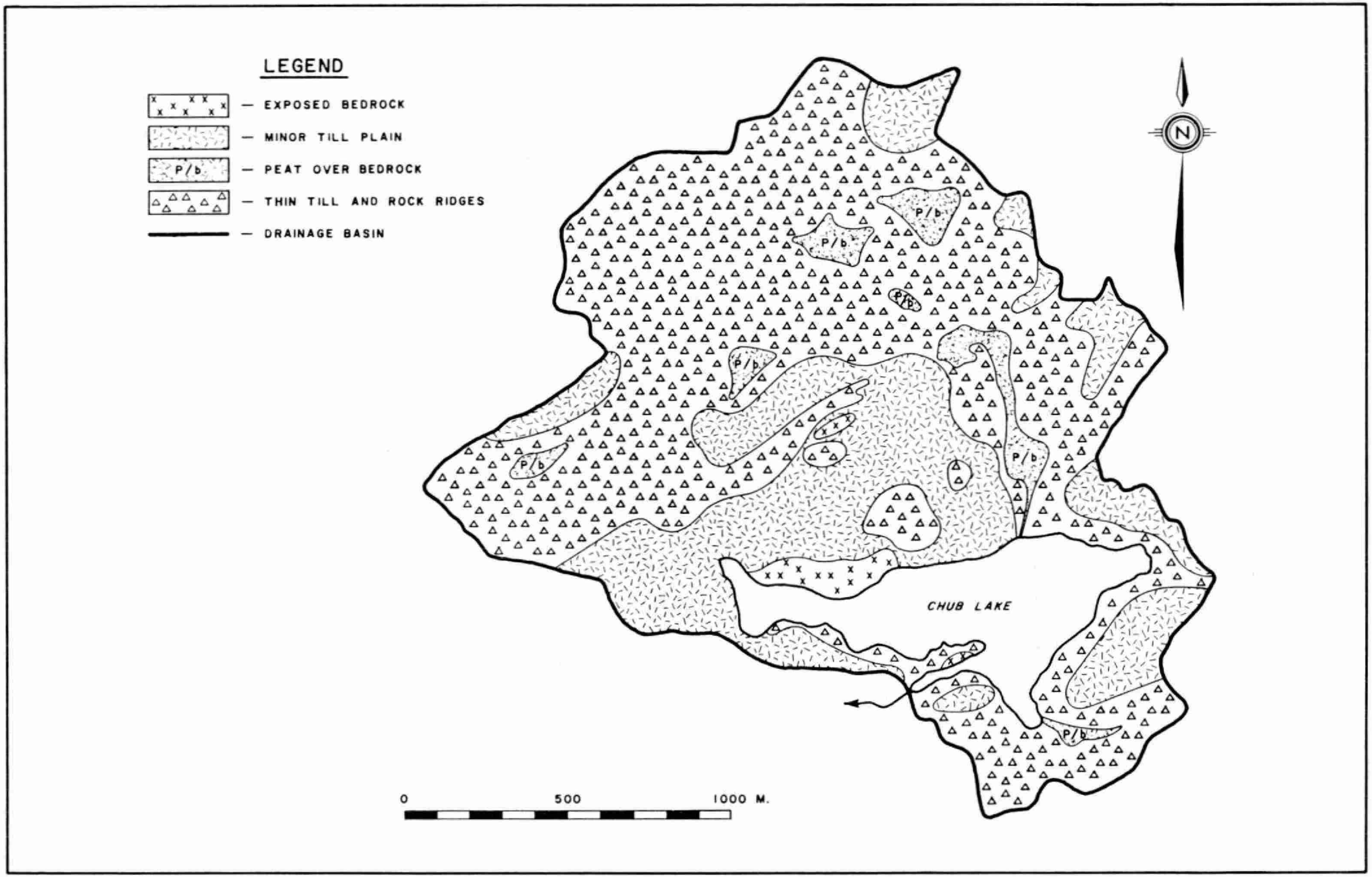

FIG. 8 SURFICIAL GEOLOGY OF THE CHUB LAKE WATERSHED.

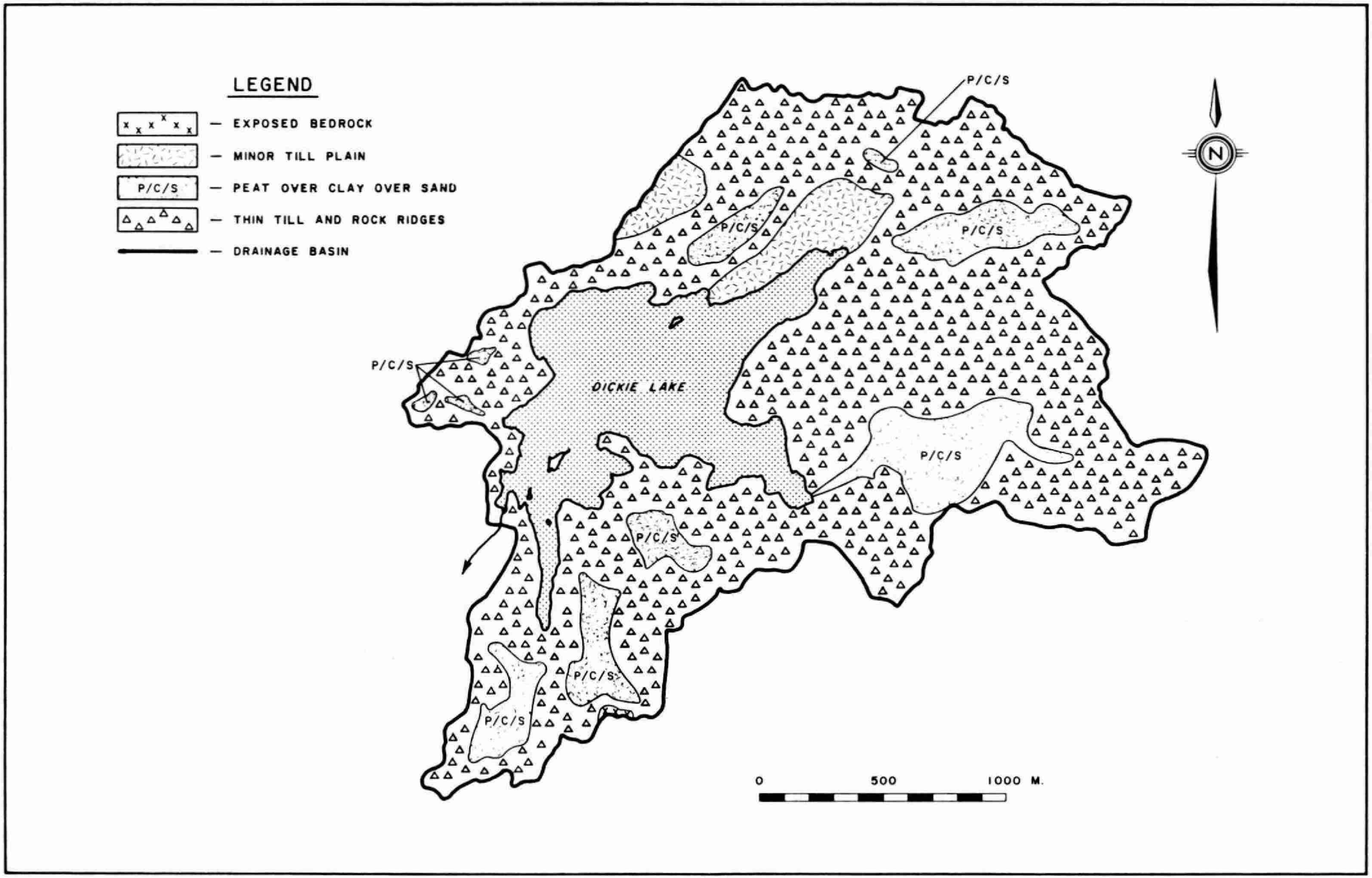

FIG. 9 SURFICIAL GEOLOGY OF THE DICKIE LAKE WATERSHED.

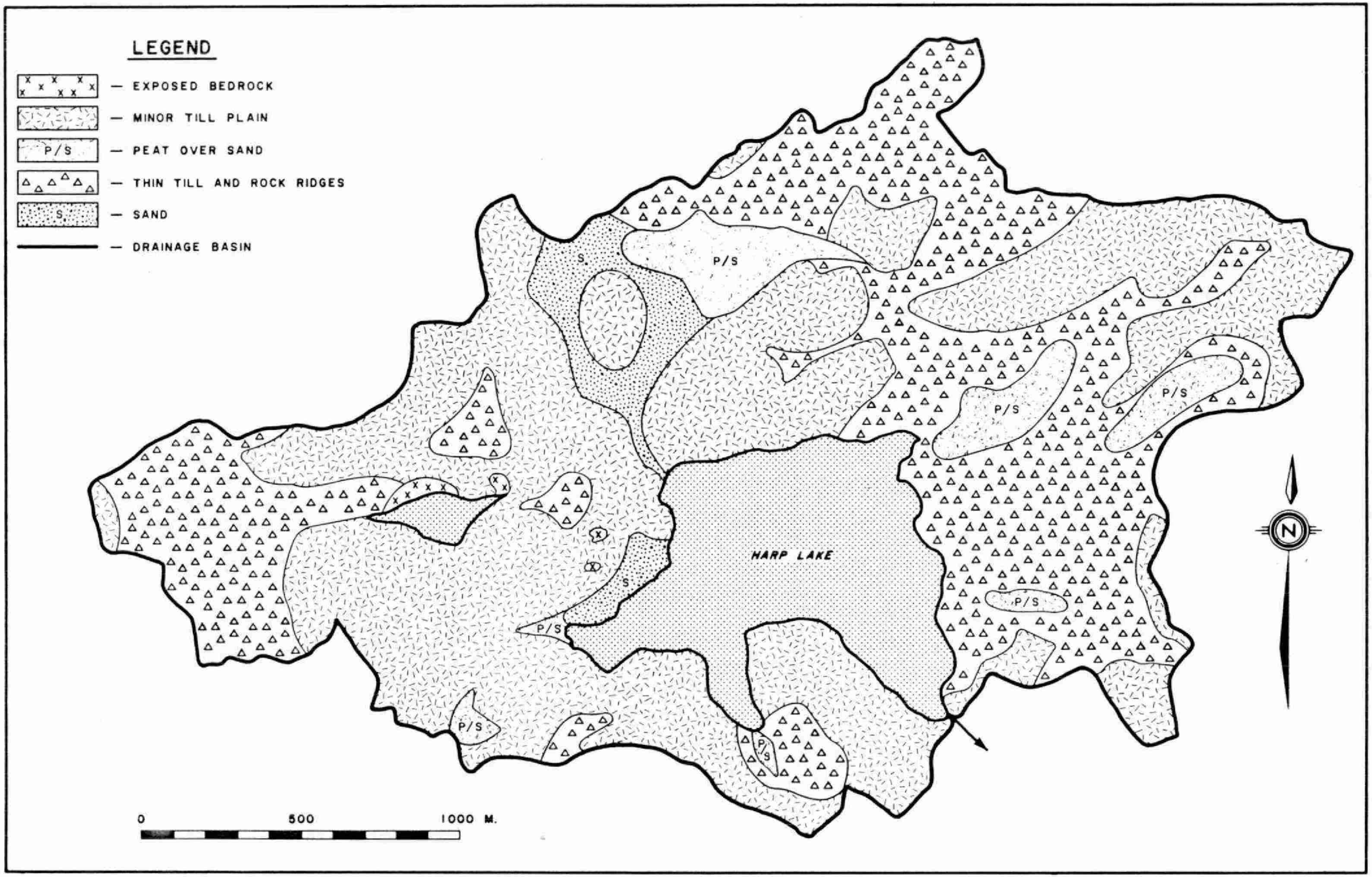

FIG. 10 SURFICIAL GEOLOGY OF THE HARP LAKE WATERSHED.

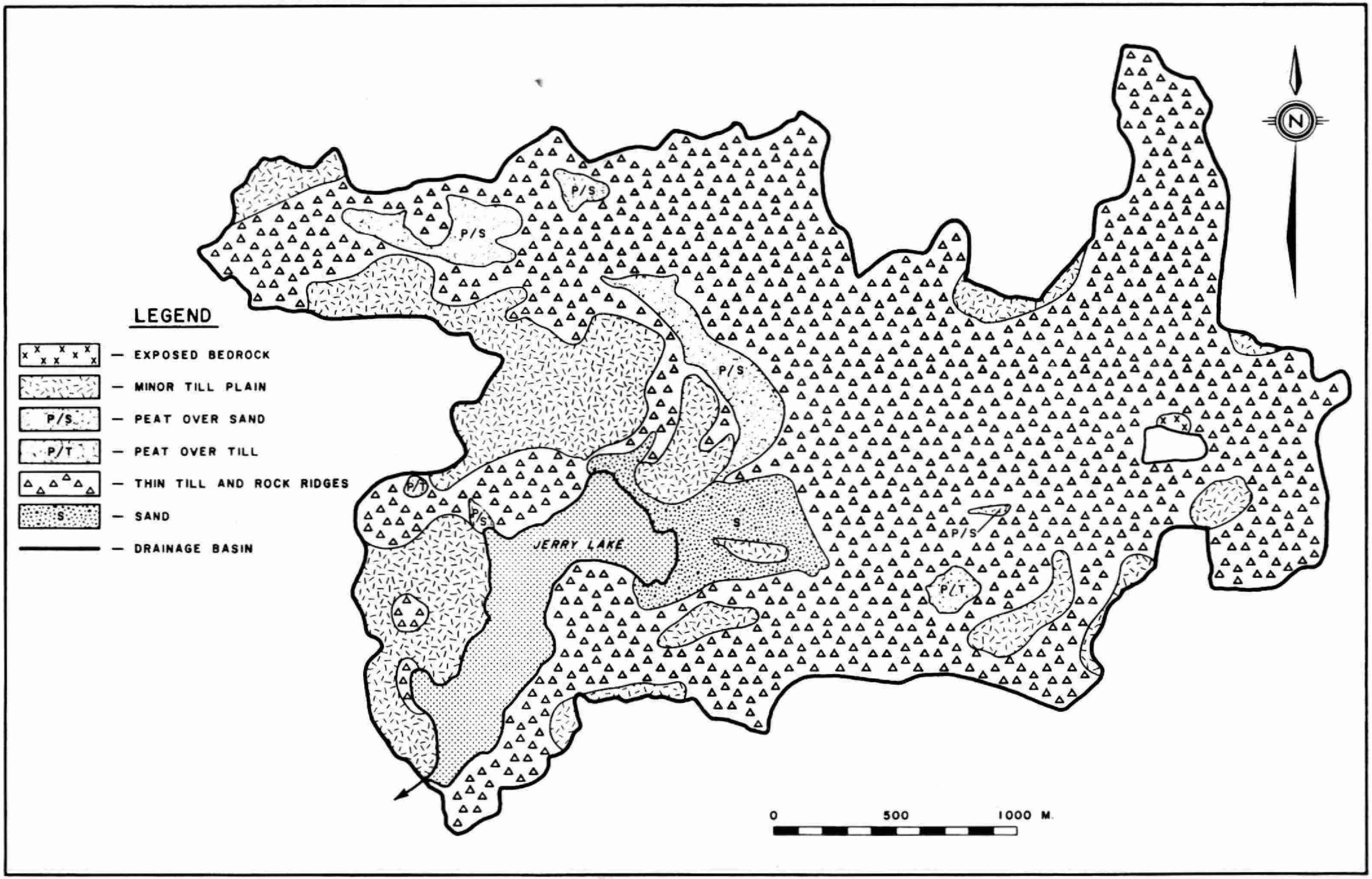

FIG. 11 SURFICIAL GEOLOGY OF THE JERRY LAKE WATERSHED.

Table 11: Percent areal extent of bedrock type of the "A" lake watersheds and subwatersheds.

Lake	Basin	Bedrock Type: Biotite Horneblende Gneiss	Diorite	Amphibolite and Schist	Migmatite	Amphibolite	Marble	Migmitite & Granite Intrusive	Gneiss & Schist	Gneiss & Skarn	Meta Arkose and Minor Marble	Biotite Gneiss, Meta Arkose & Marble
Red Chalk	1	100	-	-	-	-	-	-	-	-	-	-
	2	100	-	-	-	-	-	-	-	-	-	-
	3	100	-	-	-	-	-	-	-	-	-	-
	4	100	-	-	-	-	-	-	-	-	-	-
	Misc.	100	-	-	-	-	-	-	-	-	-	-
	Total	100	-	-	-	-	-	-	-	-	-	-
Blue Chalk	1	100	-	-	-	-	-	-	-	-	-	-
	Misc.	100	-	-	-	-	-	-	-	-	-	-
	Total	100	-	-	-	-	-	-	-	-	-	-
Chub	1	100	-	-	-	-	-	-	-	-	-	-
	2	100	-	-	-	-	-	-	-	-	-	-
	Misc.	100	-	-	-	-	-	-	-	-	-	-
	Total	100	-	-	-	-	-	-	-	-	-	-
Dickie	3	-	-	-	100	-	-	-	-	-	-	-
	5	-	-	-	100	-	-	-	-	-	-	-
	6	-	-	-	100	-	-	-	-	-	-	-
	8	-	-	-	100	-	-	-	-	-	-	-
	10	-	-	-	100	-	-	-	-	-	-	-
	11	-	-	-	100	-	-	-	-	-	-	-
	Misc.	-	-	-	100	-	-	-	-	-	-	-
	Total	-	-	-	100	-	-	-	-	-	-	-

Table 11: Percent areal extent of bedrock type of the "A" lake watersheds and subwatersheds (cont'd)

Lake	Basin	Bedrock Type										
		Biotite Horneblende Gneiss	Diorite	Amphibolite and Schist	Migmatite	Amphibolite	Marble	Migmitite & Granite Intrusive	Gneiss & Schist	Gneiss & Skarn	Meta Arkose and Minor Marble	Biotite Gneiss, Meta Arkose & Marble
Harp	1	100	-	-	-	-	-	-	-	-	-	-
	3	93.0	-	7.0	-	-	-	-	-	-	-	-
	3A	42.6	-	57.4	-	-	-	-	-	-	-	-
	4	13.2	-	86.8	-	-	-	-	-	-	-	-
	5	100	-	-	-	-	-	-	-	-	-	-
	6	100	-	-	-	-	-	-	-	-	-	-
	6A	33.3	66.7	-	-	-	-	-	-	-	-	-
	Misc.	90.3	1.4	8.4	-	-	-	-	-	-	-	-
	Total	68.5	3.1	28.4	-	-	-	-	-	-	-	-
Jerry	1	100	-	-	-	-	-	-	-	-	-	-
	2	100	-	-	-	-	-	-	-	-	-	-
	3	100	-	-	-	-	-	-	-	-	-	-
	4	100	-	-	-	-	-	-	-	-	-	-
	Misc.	94.7	5.3	-	-	-	-	-	-	-	-	-
	Total	99.5	0.5	-	-	-	-	-	-	-	-	-

Table 12: Percent areal extent of surficial types of the "A" lake watersheds and subwatersheds.

		Surficial Deposit Type									
Lake	Basin	Till (carbonate)	Minor Till Plain	Thin Till and Rock Ridges	Peat	Bedrock	Outwash	Esker	Drumlin	Sand	Pond
Red Chalk	1	-	53.2	41.1	-	-	0.8	-	-	-	4.9
	2	-	-	67.9	10.5	19.4	-	-	-	-	2.2
	3	-	81.7	2.7	9.9	1.2	-	-	-	-	4.5
	4	-	76.3	16.0	2.9	-	-	-	-	-	4.8
	Misc.	-	48.0	17.1	-	1.2	33.7	-	-	-	-
	Total	-	57.6	26.5	3.4	2.0	6.9	-	-	-	3.6
Blue Chalk	1	-	94	6	-	-	-	-	-	-	-
	Misc.	-	76.3	14.9	-	1.8	7.0	-	-	-	-
	Total	-	76.7	16.5	-	1.4	5.4	-	-	-	-
Chub	1	-	24.2	72.4	2.8	0.6	-	-	-	-	-
	2	-	16.7	75.3	8.0	-	-	-	-	-	-
	Misc.	-	62.2	32.2	0.9	4.7	-	-	-	-	-
	Total	-	32.3	61.7	4.4	1.6	-	-	-	-	-
Dickie	3	-	-	82.4	16.2	1.4	-	-	-	-	-
	5	-	-	74.6	25.4	-	-	-	-	-	-
	6	-	-	78.0	22.0	-	-	-	-	-	-
	8	-	13.7	78.1	8.2	-	-	-	-	-	-
	10	-	-	82.9	17.1	-	-	-	-	-	-
	11	-	-	79.1	20.9	-	-	-	-	-	-
	Misc.	-	11.2	87.1	1.7	-	-	-	-	-	-
	Total	-	4.7	81.4	13.9	-	-	-	-	-	-

Table 12: Percent areal extent of surficial types of the "A" lake watersheds and subwatersheds (cont'd)

		Surficial Deposit Type									
Lake	Basin	Till (carbonate)	Minor Till Plain	Thin Till and Rock Ridges	Peat	Bedrock	Outwash	Esker	Drumlin	Sand	Pond
Harp	1	-	38.5	54.6	6.9	-	-	-	-	-	-
	3	-	79.5	11.2	9.3	-	-	-	-	-	-
	3A	-	97.1	-	2.9	-	-	-	-	-	-
	4	-	56.1	32.8	-	0.9	-	-	-	7.5	2.7
	5	-	34.5	48.6	13.3	-	-	-	-	3.6	-
	6	-	45.2	54.8	-	-	-	-	-	-	-
	6A	-	6.6	84.9	8.5	-	-	-	-	-	-
	Misc.	-	69.5	23.4	0.6	0.3	-	-	-	6.2	-
	Total	-	49.8	38.5	6.3	0.3	-	-	-	4.3	0.8
Jerry	1	-	77.4	22.6	-	-	-	-	-	-	-
	2	-	53.0	43.7	3.3	-	-	-	-	-	-
	3	-	13.4	78.4	5.2	0.1	-	-	-	2.5	0.4
	4	-	13.7	83.5	-	-	-	-	-	2.8	-
	Misc.	-	40.8	46.9	-	-	-	-	-	12.3	-
	Total	-	19.8	72.2	4.2	0.1	-	-	-	3.4	0.3

2. "B" Lakes

The bedrock geology and basin designation of the "B" lake watersheds and subwatersheds are given in Figures 12 through 18. The percent areal extent of the bedrock types for each B lake watershed and subwatershed is presented in Table 13. The "B" lake watersheds show a greater range in bedrock composition than the "A" lakes watersheds described previously. The bedrock of the Glen Lake basin is composed of marble in the northern section which contacts gneiss in the southern sector. The gneiss found in the Glen Lake basin extends through the entire Basshaunt Lake watershed. Bedrock geology of the Solitaire, Little Clear and Buck watersheds is dominated by interbedded horneblende gneiss, biotite gneiss and occasional thin schist beds. An oval outcrop of garnet rich amphibolite occurs at the intersection of the three watersheds. A smaller amphibolite outcrop also occurs at the north-west boundary of Little Clear subwatershed #1. The Bigwind, Crosson and Gullfeather watersheds are composed of migmitite and granite intrusive bedrock. The original meta-sedimentary bedrock has been replaced or severely altered by felsic intrusions resulting in felsic quartz gneiss and/or migmitite. The Gullfeather and to a lesser extent Crosson basin are unique in that the sulphide minerals pyrite and pyrotite are found in small quantities dispersed throughout the bedrock. The Walker Lake watershed consists of granitized biotite gneiss interbedded with granitized horneblende gneiss.

The surficial geology of the "B" lake watersheds and subwatersheds is presented in Figures 19 through 25. The percent areal extent of the surficial deposits is given in Table 14. The "B" lake watersheds are generally covered by a till veneer of varying thickness. The Glen Lake watershed, with the exception of a small sand lens in the northern section is composed entirely of carbonate rich till. The frequency of marble pebbles and boulders decreases southward and occurs only rarely in the southern portion of the Basshaunt Lake watershed. The steeply dipping western portion of

the Basshaunt watershed is covered with a thin till veneer while the more gently sloping eastern portion has a minor till plain.

Sand and gravel deposits of fluvial origin link the northern bays of Bushwolf Lake to the two eastern bays of Basshaunt Lake. The drainage basin of Solitaire, Little Clear and Buck are dominated by minor till plain. The Solitaire and Little Clear watersheds also have significant sand and gravel deposits which are greater than five meters in depth. Little Clear is unique among the B lakes in that it is surrounded by spillway deposits which also make up greater than 20 percent of the watershed area. The surficial geology of the Gullfeather and Crosson basins is composed of peat and ponded areas surrounded by expanses of thin till and rock ridges. The minor till plains which cover a large portion of the Bigwind basin are of much less significance in the Crosson and Gullfeather basins. Generally the larger sites of peat accumulation in the Bigwind, Crosson and Gullfeather basin are extensions of the existing water bodies. The Walker Lake drainage basin is covered by a relatively continuous minor till plain. Exceptions include a raised beach complex at the mouth of the major inflowing stream and isolated areas of thin till, rock ridges, and peat.

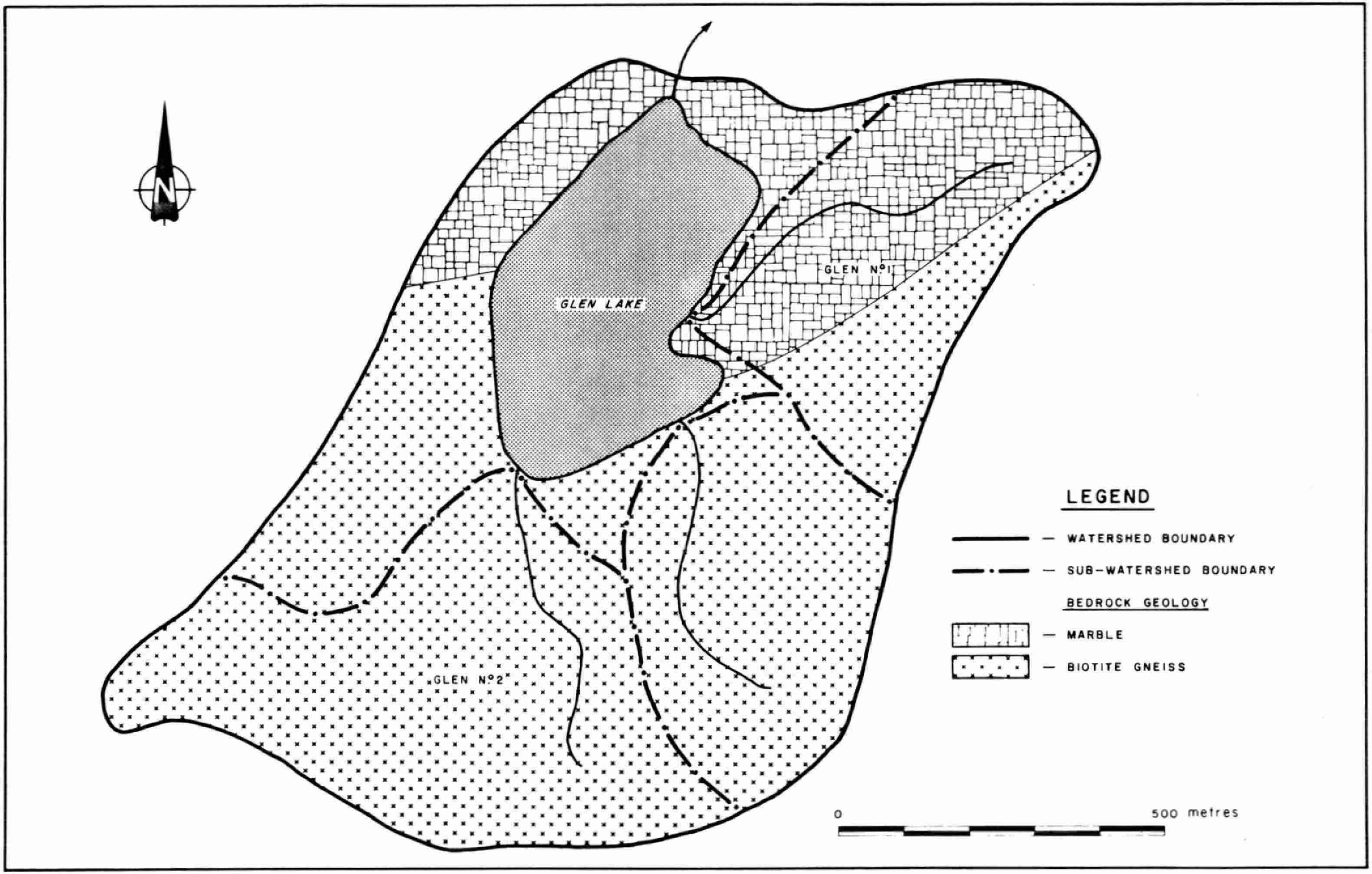

FIGURE 12 - BEDROCK GEOLOGY AND BASIN DESIGNATION OF THE GLEN LAKE WATERSHED

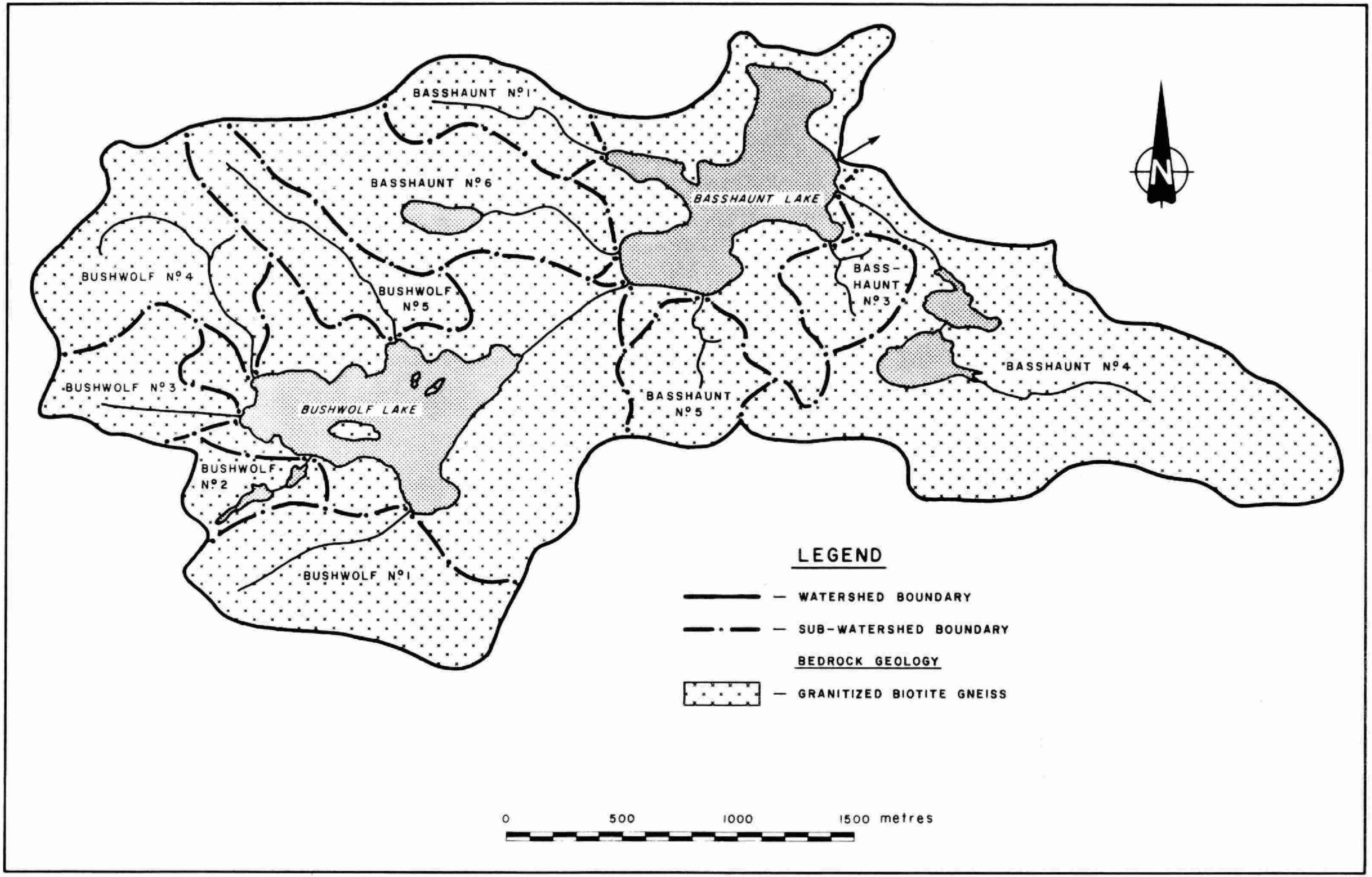

FIGURE 13 – BEDROCK GEOLOGY AND BASIN DESIGNATION OF THE BASSHAUNT LAKE WATERSHED

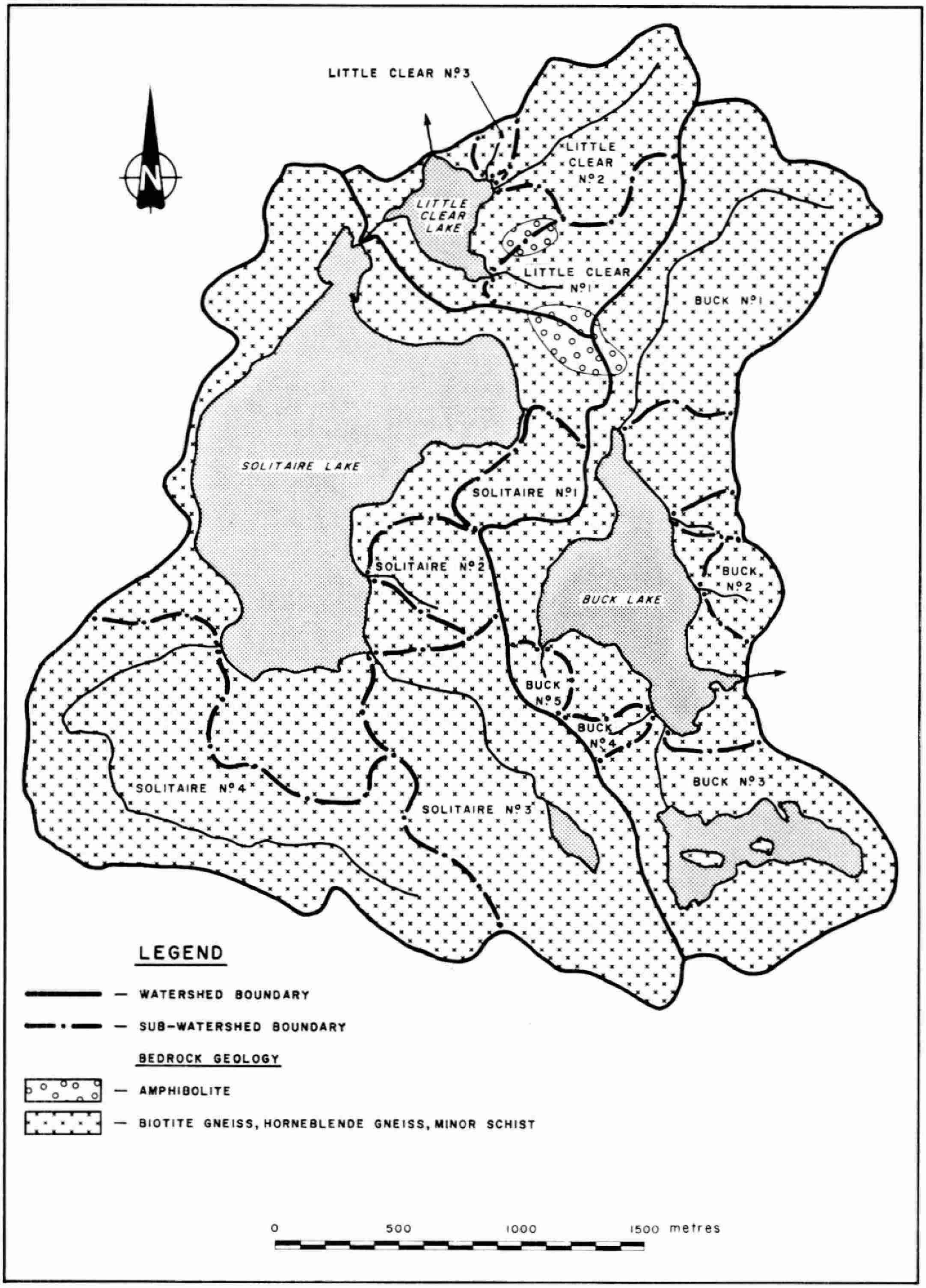

FIGURE 14 - BEDROCK GEOLOGY AND BASIN DESIGNATIONS OF THE SOLITAIRE, BUCK AND LITTLE CLEAR LAKE WATERSHEDS

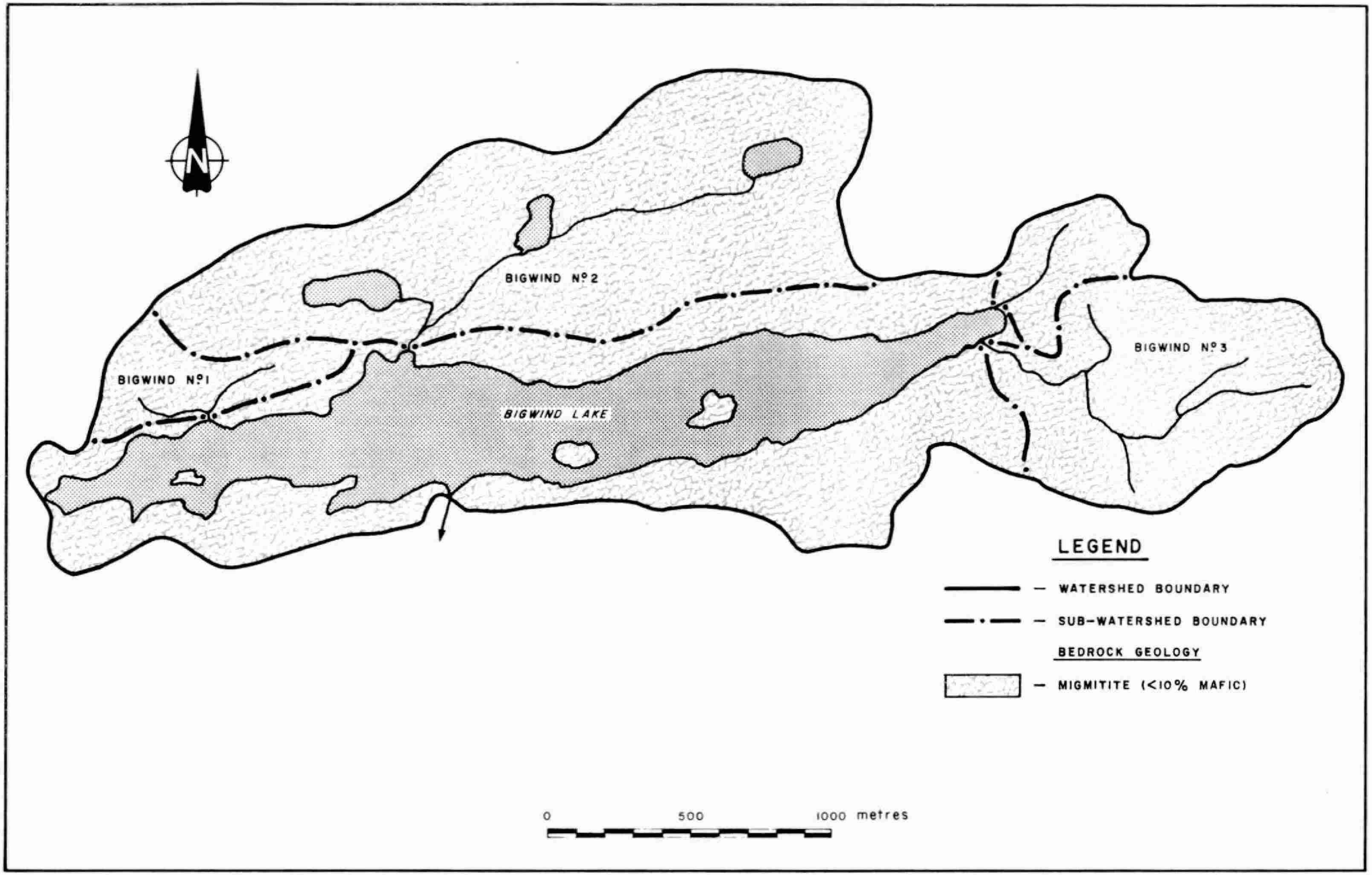

FIGURE 15 – BEDROCK GEOLOGY AND BASIN DESIGNATION OF THE BIGWIND LAKE WATERSHED

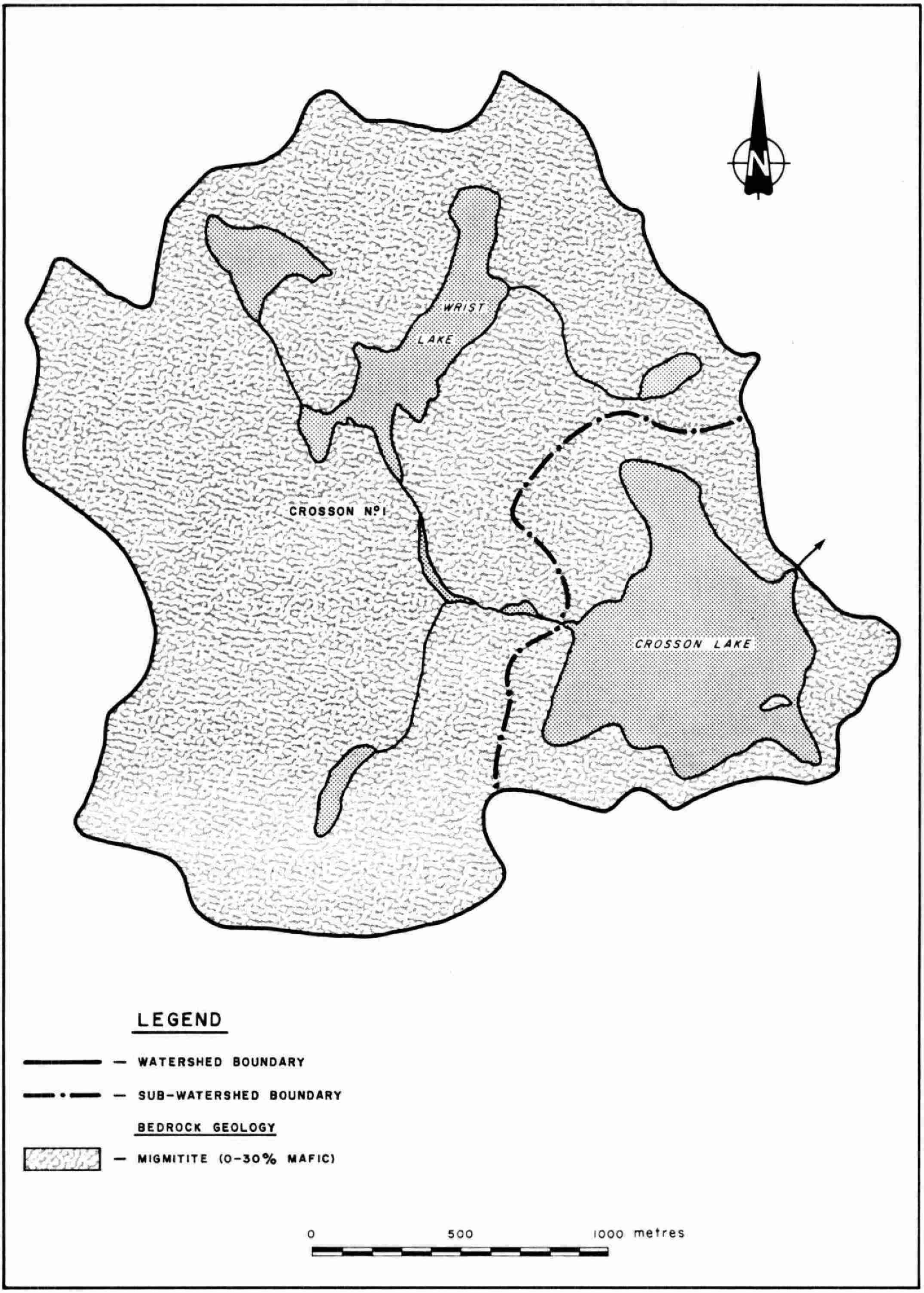

FIGURE 16 - BEDROCK GEOLOGY AND BASIN DESIGNATION OF THE CROSSON LAKE WATERSHED

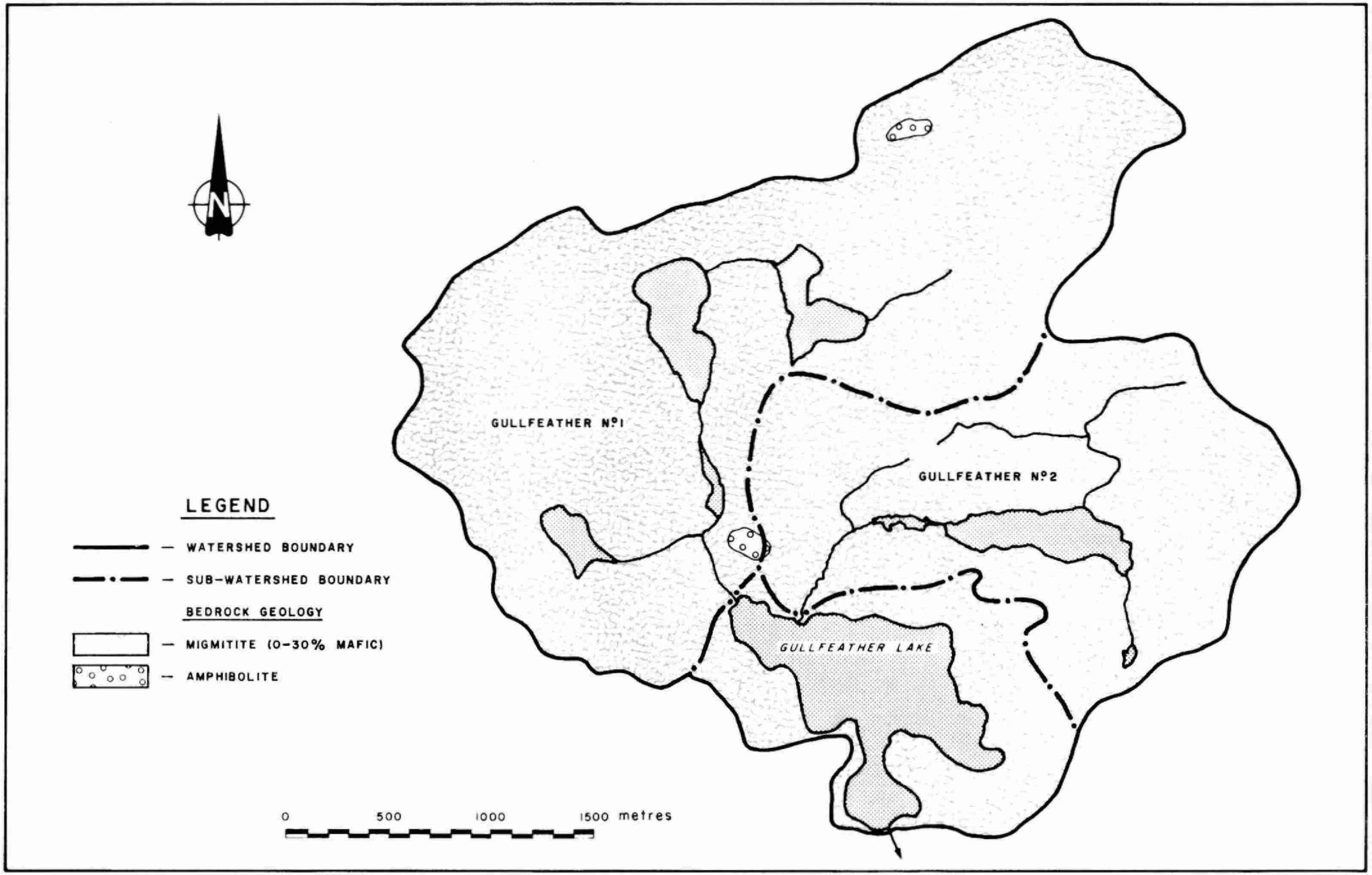

FIGURE 17 - BEDROCK GEOLOGY AND BASIN DESIGNATION OF THE GULLFEATHER LAKE WATERSHED

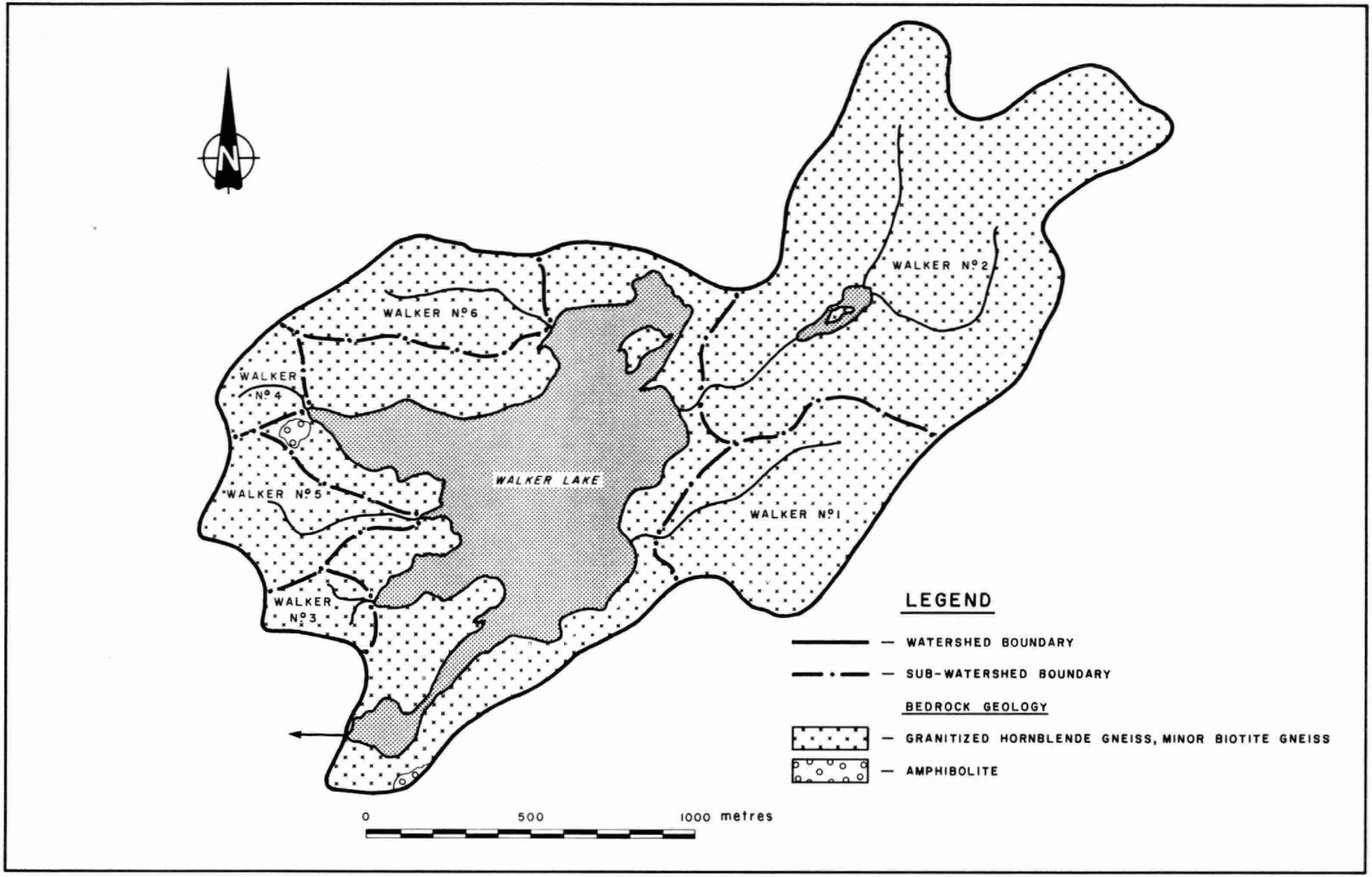

FIGURE 18 - BEDROCK GEOLOGY AND BASIN DESIGNATION OF THE WALKER LAKE WATERSHED

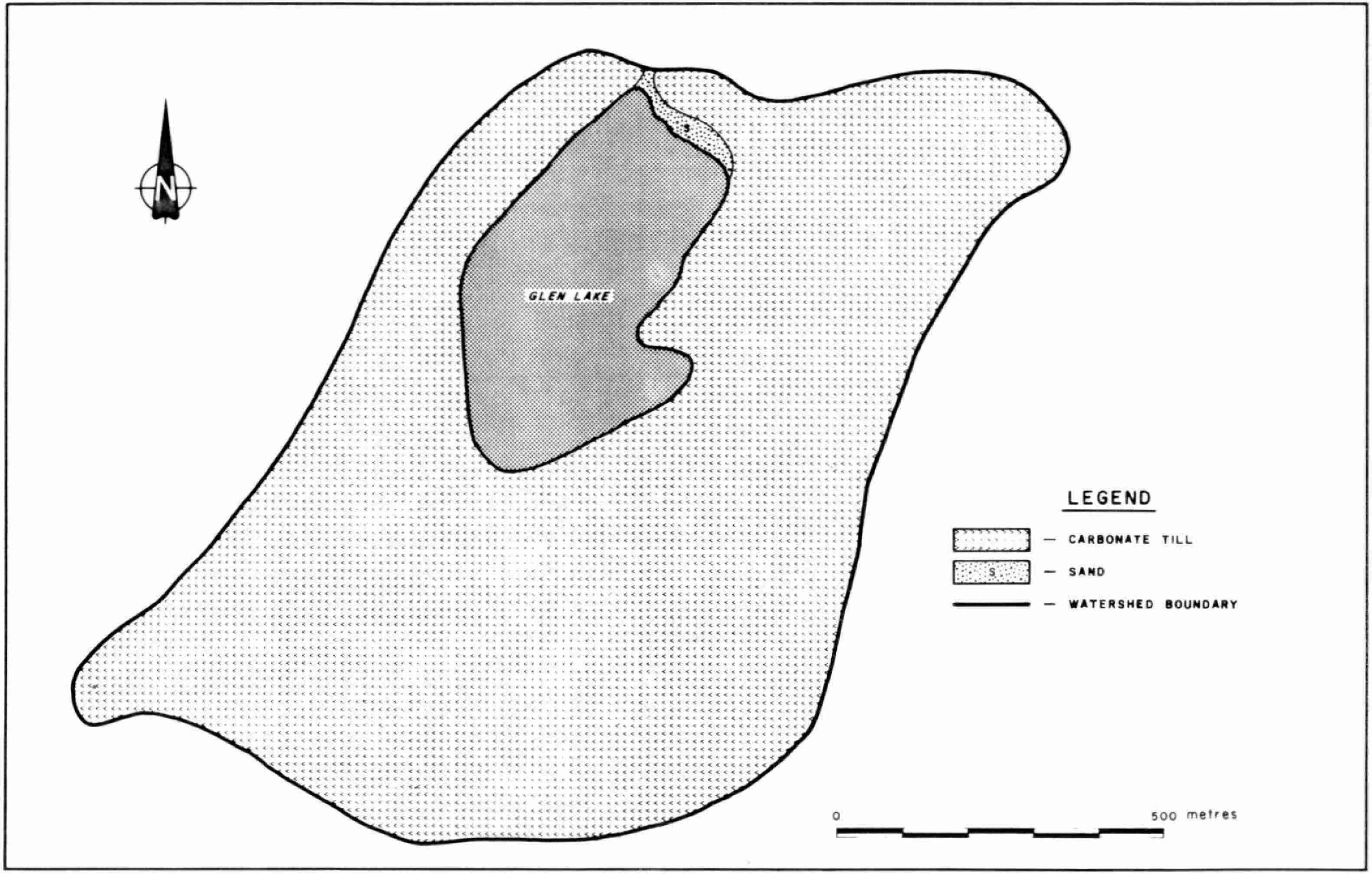

FIGURE 19 – SURFICIAL GEOLOGY OF THE GLEN LAKE WATERSHED

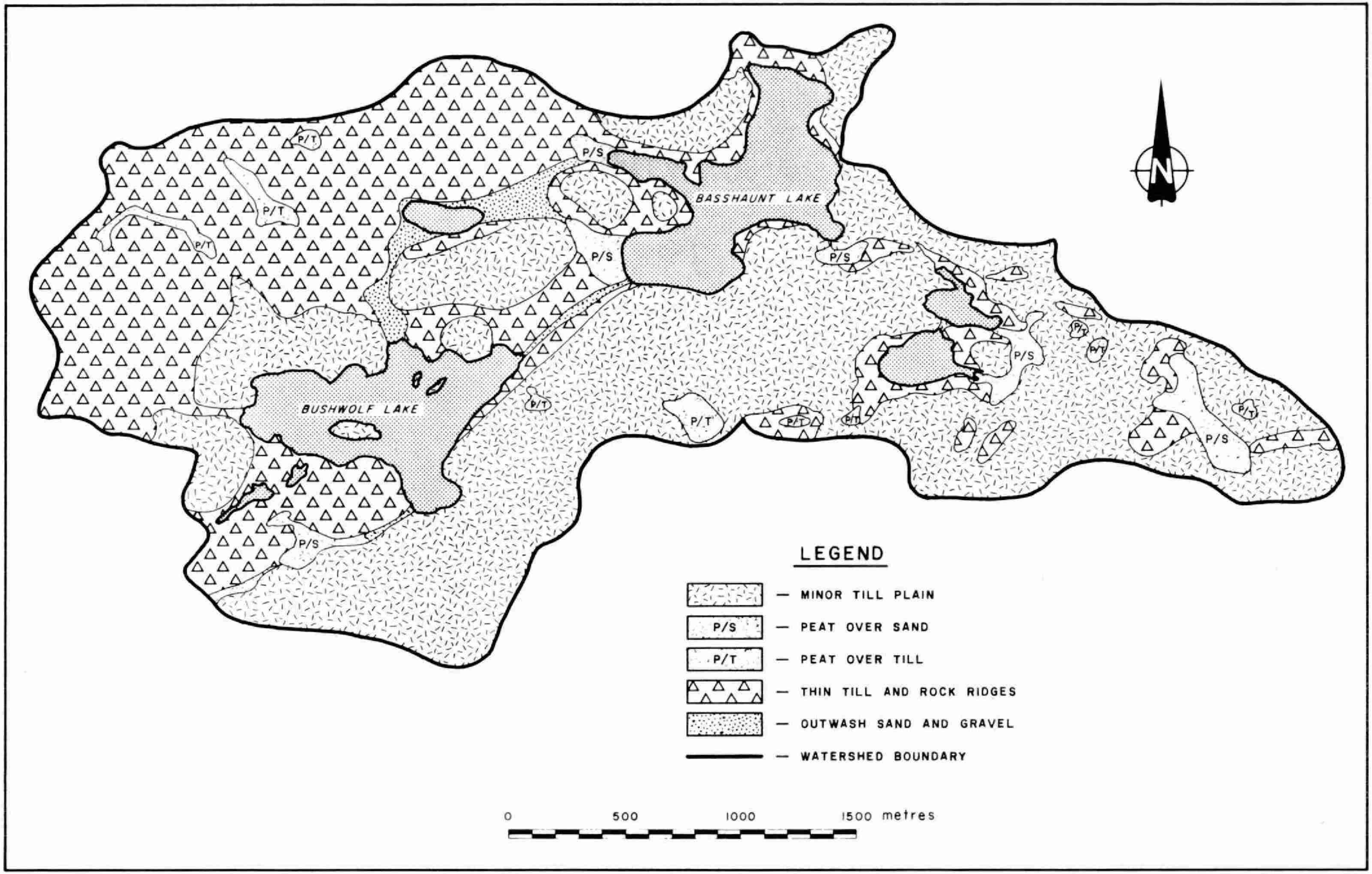

FIGURE 20 – SURFICIAL GEOLOGY OF THE BASSHAUNT LAKE WATERSHED

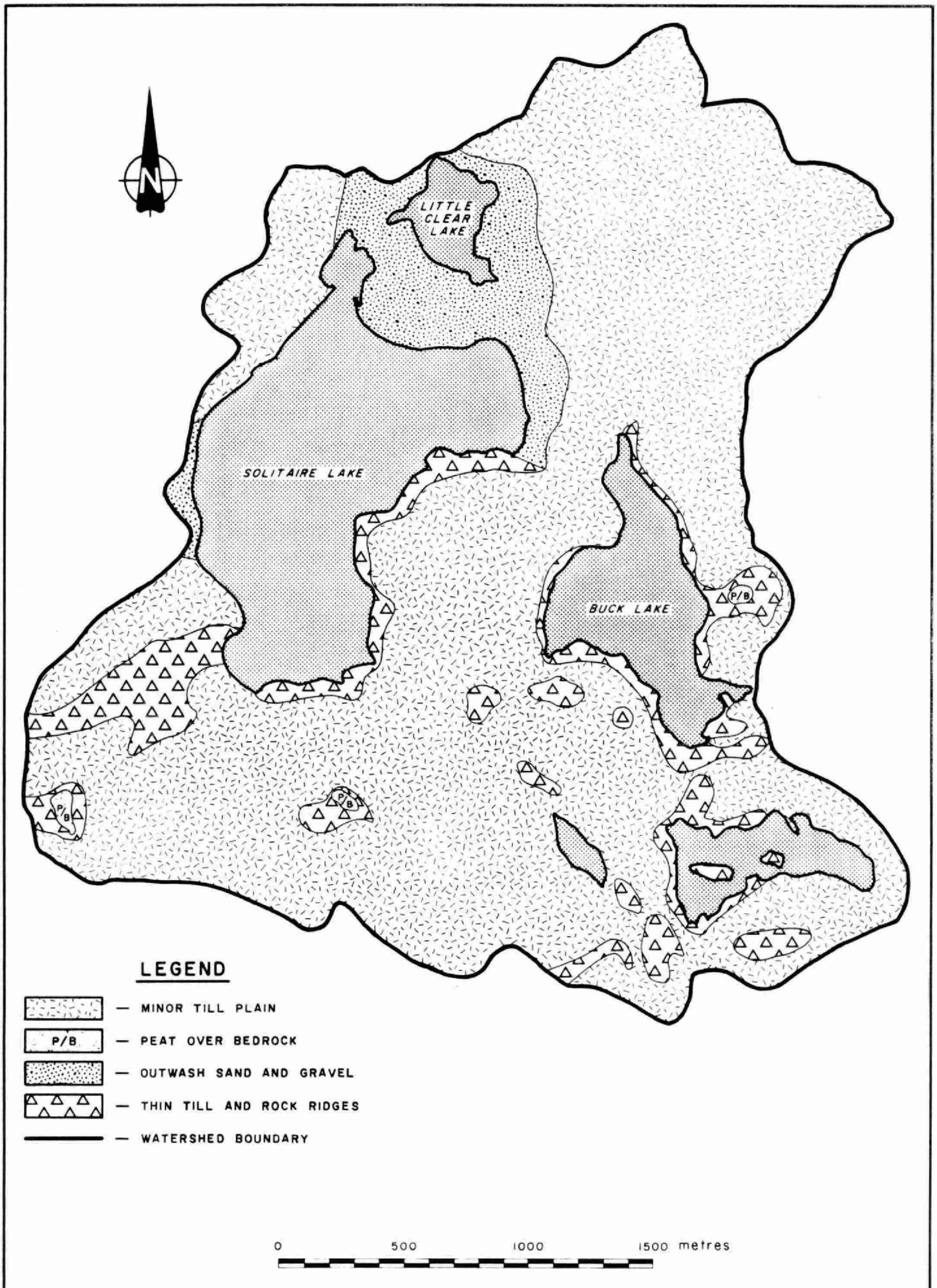

FIGURE 21 - SURFICIAL GEOLOGY OF THE SOLITAIRE, BUCK AND LITTLE CLEAR LAKE WATERSHEDS

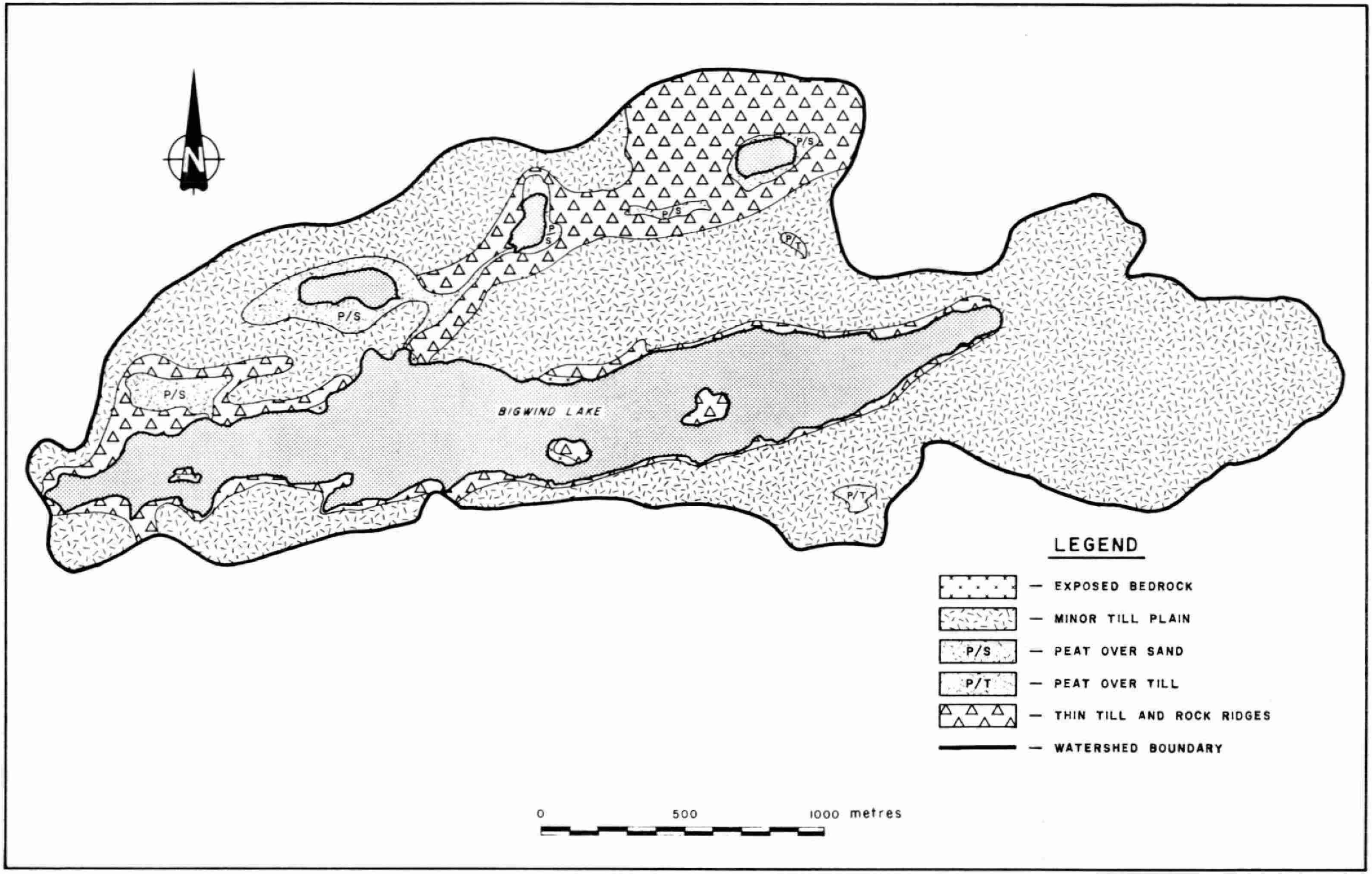

FIGURE 22 – SURFICIAL GEOLOGY OF THE BIGWIND LAKE WATERSHED

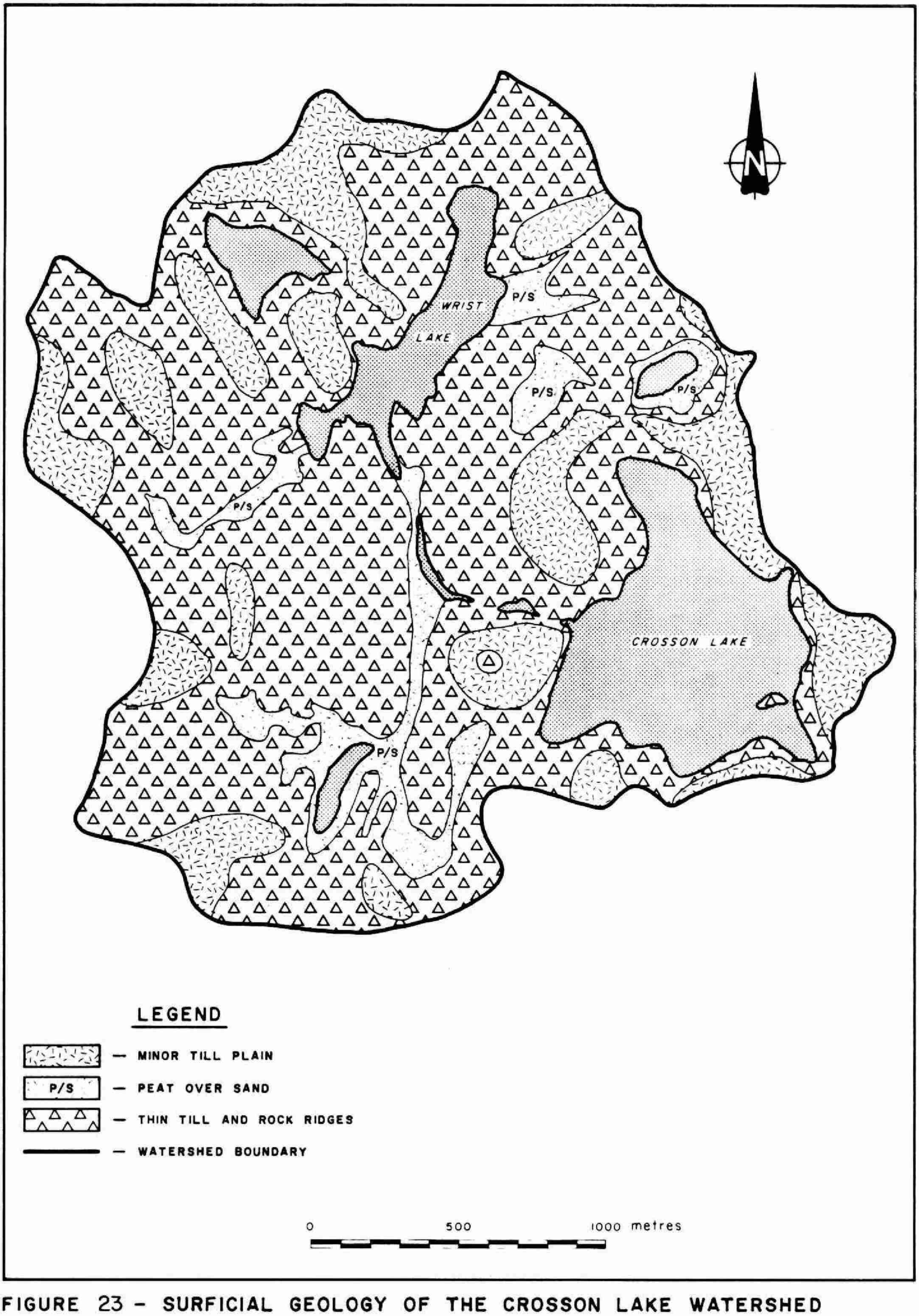

FIGURE 23 - SURFICIAL GEOLOGY OF THE CROSSON LAKE WATERSHED

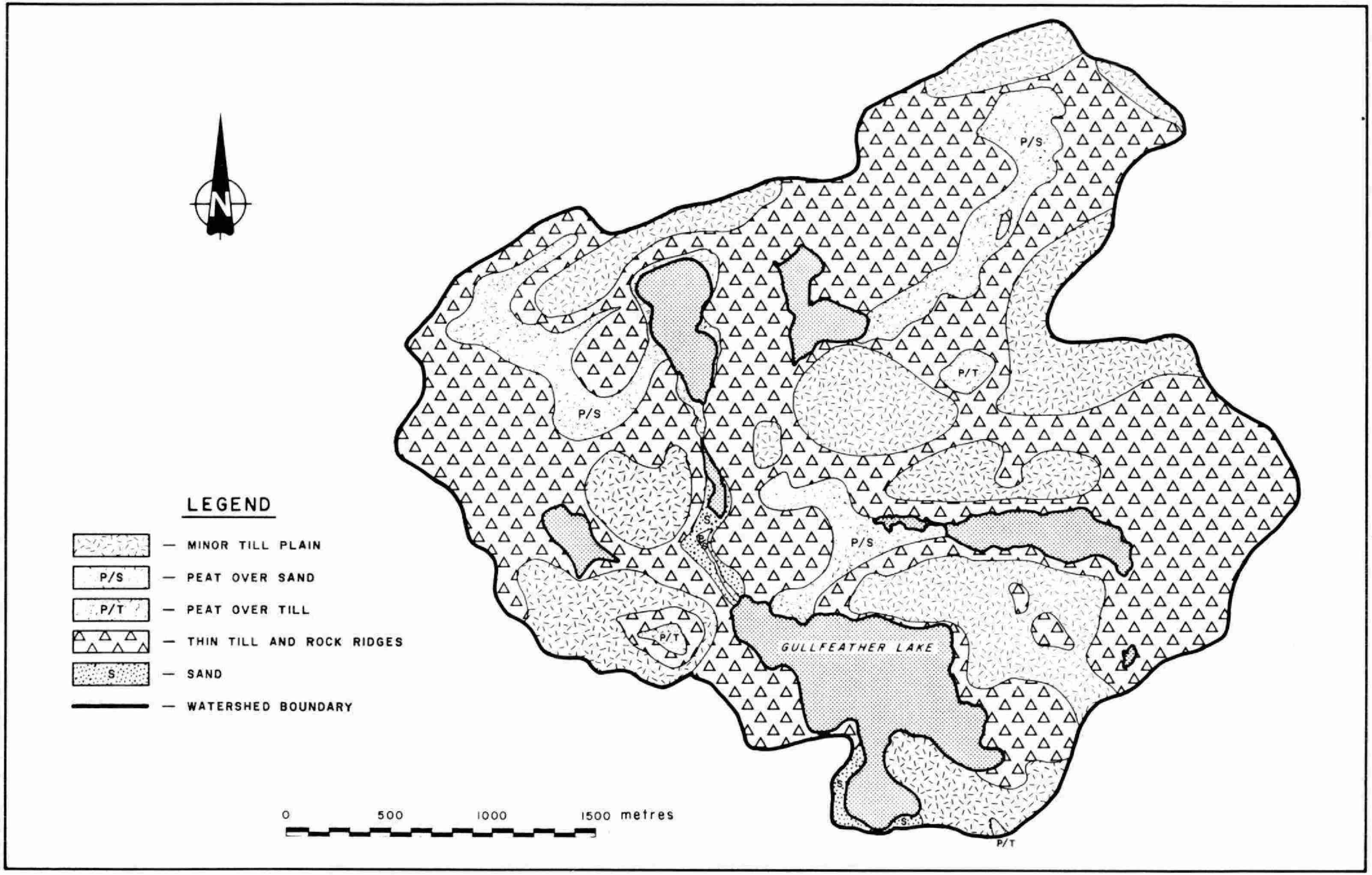

FIGURE 24 - SURFICIAL GEOLOGY OF THE GULLFEATHER LAKE WATERSHED

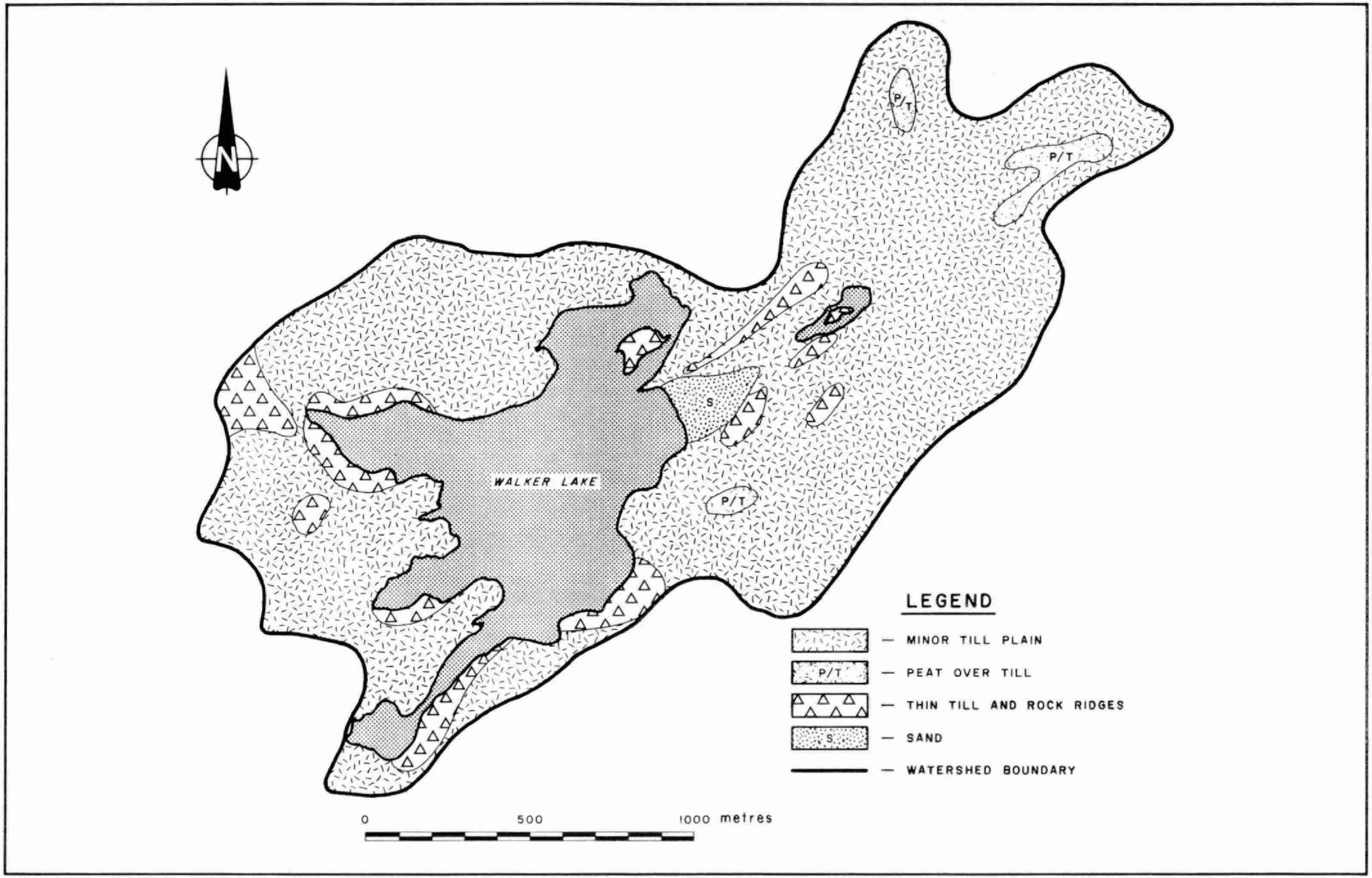

FIGURE 25 - SURFICIAL GEOLOGY OF THE WALKER LAKE WATERSHED

Table 13: Percent areal extent of bedrock types of the "B" lake watersheds and subwatersheds.

Lake Basin		Bedrock Geology % Composition								
		Diorite	Migmitite	Amphibolite	Marble	Migmitite & Granite Intrusive	Gneiss, Gneiss & Schist	Gneiss & Skarn	Meta-Arkose and Minor Marble	Hornblende Biotite Gneiss
Glen	1	-	-	-	62.1	-	-	37.9	-	-
	2	-	-	-	-	-	-	100	-	-
	Misc.	-	-	-	20.8	-	-	79.2	-	-
	Total	-	-	-	22.7	-	-	77.3	-	-
Basshaunt	1	-	-	-	-	-	-	-	-	100
	*2	-	-	-	-	-	-	-	-	100
	3	-	-	-	-	-	-	-	-	100
	4	-	-	-	-	-	-	-	-	100
	5	-	-	-	-	-	-	-	-	100
	6	-	-	-	-	-	-	-	-	100
	Misc.	-	-	-	-	-	-	-	-	100
	Total	-	-	-	-	-	-	-	-	100
*Bushwolf	1	-	-	-	-	-	-	-	-	100
	2	-	-	-	-	-	-	-	-	100
	3	-	-	-	-	-	-	-	-	100
	4	-	-	-	-	-	-	-	-	100
	5	-	-	-	-	-	-	-	-	100
	Misc.	-	-	-	-	-	-	.2	-	98
	Total	-	-	-	-	-	-	.7	-	99.3

* Bushwolf outflow is Basshaunt #2 inlet.

Table 13: Percent areal extent of bedrock types of the "B" lake watersheds and subwatersheds (cont'd)

Lake Basin		Bedrock Geology % Composition								
		Diorite	Migmitite	Amphibolite	Marble	Migmitite & Granite Intrusive	Gneiss, Gneiss & Schist	Gneiss & Skarn	Meta-Arkose and Minor Marble	Hornblende Biotite Gneiss
Solitaire	1	-	-	-	-	-	100	-	-	-
	2	-	-	-	-	-	100	-	-	-
	3	-	-	-	-	-	100	-	-	-
	4	-	-	-	-	-	100	-	-	-
	Misc.	-	-	1.	-	-	99	-	-	-
	Total	-	-	.3	-	-	99.7	-	-	-
Little Clear	1	-	-	9	-	-	91	-	-	-
	2	-	-	-	-	-	100	-	-	-
	3	-	-	-	-	-	100	-	-	-
	Misc.	-	-	3.0	-	-	97	-	-	-
	Total	-	-	4.4	-	-	95.6	-	-	-
Buck	1	-	-	2	-	-	-	-	-	98
	2	-	-	-	-	-	-	-	-	100
	3	-	-	-	-	-	-	-	-	100
	4	-	-	-	-	-	-	-	-	100
	5	-	-	-	-	-	-	-	-	100
	Misc.	-	-	-	-	-	-	-	-	100
	Total	-	-	-	-	-	-	-	-	100
Bigwind	1	-	-	-	-	100	-	-	-	-
	2	-	-	-	-	100	-	-	-	-
	3	-	-	-	-	100	-	-	-	-
	Misc.	-	-	-	-	100	-	-	-	-
	Total	-	-	-	-	100	-	-	-	-

Table 13: Percent areal extent of bedrock types of the "B" lake watersheds and subwatersheds (cont'd)

Lake Basin		Bedrock Geology % Composition								
		Diorite	Migmitite	Amphibolite	Marble	Migmitite & Granite Intrusive	Gneiss, Gneiss & Schist	Gneiss & Skarn	Meta-Arkose and Minor Marble	Hornblende Biotite Gneiss
Crosson	1	-	-	-	-	100	-	-	-	-
	Misc.	-	-	-	-	100	-	-	-	-
	Total	-	-	-	-	100	-	-	-	-
Gull-feather	1	-	-	.4	-	99.6	-	-	-	-
	2	-	-	.1	-	99.9	-	-	-	-
	Misc.	-	-	-	-	100	-	-	-	-
	Total	-	-	.2	-	99.8	-	-	-	-
Walker	1	-	-	-	-	-	-	-	-	100
	2	-	-	-	-	-	-	-	-	100
	3	-	-	-	-	-	-	-	-	100
	4	-	-	-	-	-	-	-	-	100
	5	-	-	-	-	-	-	-	-	100
	6	-	-	-	-	-	-	-	-	100
	Misc.	-	-	1.1	-	-	-	-	-	98.9
	Total	-	-	.3	-	-	-	-	-	99.7

Table 14: Percent areal extent of surficial deposit types of the "B" lake watersheds and subwatersheds.

Lake Basin		Surficial Geology % Composition										
		Till Carbonate	Minor Till Plain	Thin Till and Rock Ridges	Peat Sand	Peat Till	Bedrock	Outwash	Esker	Drumlin	Sand	Pond
Glen	1	100	-	-	-	-	-	-	-	-	-	-
	2	100	-	-	-	-	-	-	-	-	-	-
	Misc.	99.7	-	-	-	-	-	-	-	-	.3	-
	Total	99.9	-	-	-	-	-	-	-	-	.1	-
Basshaunt	1	Trace	13.1	80.1	5.5	-	-	1.3	-	-	-	-
	*2	Trace	52.2	29.2	1.2	1.6	-	3.7	-	-	-	12.1
	3	Trace	87.2	6.6	6.3	-	-	-	-	-	-	-
	4	Trace	71.4	15.5	6.5	1.1	-	-	-	-	-	5.5
	5	Trace	88.7	-	-	11.3	-	-	-	-	-	-
	6	Trace	18.1	60.5	4.4	1.0	-	11.6	-	-	-	4.4
	Misc.	Trace	75.9	22.9	1.2	-	-	-	-	-	-	-
	Total	-	56.5	28.4	3.0	1.6	-	2.9	-	-	-	7.6
*Bushwolf	1	-	76.0	22.9	1.1	-	-	-	-	-	-	-
	2	-	51.3	41.1	-	-	-	-	-	-	7.6	-
	3	-	13.0	87.0	-	-	-	-	-	-	-	-
	4	-	7.8	87.9	-	4.3	-	-	-	-	-	-
	5	-	15.9	69.8	-	7.3	-	7.0	-	-	-	-
	Misc.	-	78.4	19.7	-	.5	-	1.4	-	-	-	-
	Total	-	48.8	46.6	1.2	.2	-	1.4	-	-	2.8	-

* Bushwolf outflow is Basshaunt #2 inlet.

Table 14: Percent areal extent of surficial deposit types of the "B" lake watersheds and subwatersheds (cont'd)

Lake Basin		Surficial Geology % Composition										
		Till Carbonate	Minor Till Plain	Thin Till and Rock Ridges	Peat Sand	Peat Till	Bedrock	Outwash	Esker	Drumlin	Sand	Pond
Solitaire	1	-	83.7	3.0	-	-	-	13.3	-	-	-	-
	2	-	99.9	.1	-	-	-	-	-	-	-	-
	3	-	89.9	7.6	-	-	-	-	-	-	-	2.5
	4	-	82.9	17.1	-	-	-	-	-	-	-	-
	Misc.	-	69.6	11.5	-	-	-	18.9	-	-	-	-
	Total	-	81.2	11.4	-	-	-	6.7	-	-	-	0.7
Little Clear	1	-	79.6	-	-	-	-	20.4	-	-	-	-
	2	-	98.5	-	-	-	-	1.5	-	-	-	-
	3	-	65.6	-	-	-	-	34.4	-	-	-	-
	Misc.	-	56.2	-	-	-	-	43.8	-	-	-	-
	Total	-	75.2	-	-	-	-	24.8	-	-	-	-
Buck	1	-	100	-	-	-	-	-	-	-	-	-
	2	-	34.6	59.5	-	5.9*	-	-	-	-	-	-
	3	-	69.8	8.6	-	-	-	-	-	-	-	21.6
	4	-	99.9	.1	-	-	-	-	-	-	-	-
	5	-	61.0	39.0	-	-	-	-	-	-	-	-
	Misc.	-	81.3	18.7	-	-	-	-	-	-	-	-
	Total	-	86.6	10.5	-	2.4	-	-	-	-	-	0.5
Bigwind	1	-	49.5	32.1	18.4	-	-	-	-	-	-	-
	2	-	56.8	33.8	8.5	1.1	-	-	-	-	-	-
	3	-	100	-	-	-	-	-	-	-	-	-
	Misc.	-	83.7	16.1	-	.1	.1	-	-	-	-	-
	Total	-	73.4	21.0	4.4	1.2	-	-	-	-	-	-

Table 14: Percent areal extent of surficial deposit types of the "B" lake watersheds and subwatersheds (cont'd)

Lake Basin		Surficial Geology % Composition										
		Till Carbonate	Minor Till Plain	Thin Till and Rock Ridges	Peat Sand	Peat Till	Bedrock	Outwash	Esker	Drumlin	Sand	Pond
Crosson	1	-	17.1	67.1	8.6	-	-	-	-	-	-	7.2
	Misc.	-	38.3	61.7	-	-	-	-	-	-	-	-
	Total	-	20.0	66.4	7.4	-	-	-	-	-	-	6.2
Gull-feather	1	-	22.9	56.5	12.6	1.0	-	-	-	-	1.0	6.0
	2	-	27.6	60.5	5.9	-	-	-	-	-	-	6.0
	Misc.	-	44.7	49.4	1.0	0.4	-	-	-	-	4.5	-
	Total	-	33.4	50.4	9.3	0.6	-	-	-	-	0.9	5.4
Walker	1	-	94.8	2.6	-	2.6	-	-	-	-	-	-
	2	-	91.7	3.6	-	2.1	-	-	-	-	2.6	-
	3	-	100	-	-	-	-	-	-	-	-	-
	4	-	49.3	50.7	-	-	-	-	-	-	-	-
	5	-	94.5	5.5	-	-	-	-	-	-	-	-
	6	-	100	-	-	-	-	-	-	-	-	-
	Misc.	-	82.1	16.2	-	-	-	-	-	-	1.7	-
	Total	-	90.3	8.0	-	1.2	-	-	-	-	0.5	-

3. Export Streams

The bedrock geology and drainage basin designations of the nine "export" stream basins are presented in Figures 26 through 33. The percent areal extent of the export basin bedrock types is given in Table 15. The export streams have varying quantities of carbonate metasedimentary rocks present in their watersheds. Differential glacial abrasion have weathered most of the larger marble beds up to sixty meters below adjacent silicate bedrock ridges. Hence the stream channels are often underlain by carbonate metasediments and the basin rims consist of silicate metasediments. The Twelve Mile North Inflow #1 watershed is centered by a north-south striking marble bed which also hosts the main stream channel. The east-west flanks of the watershed consist of biotite gneiss, meta-arkose and skarn which is associated with the marble and silicate metasedimentary contacts. Thin beds of marble are also found interbedded with arkose and gneiss in proximity to the major marble bed. The Twelve Mile Lake south inflow #1 has marble outcropping in the north-west corner with biotite gneiss, arkose, skarn and thin marble beds forming the remainder of the basin geology. The bedrock geology of Beech Lake inflow #1 is similar to that of the adjoining Twelve Mile north inflow #1. The Beech Lake inflow #1 has a continuation of the marble bed found in the Twelve Mile north inflow #1 basin although it is somewhat greater in width in the Beech Lake subwatershed.

The Haliburton Lake inflow #12 watershed is granitized biotite gneiss bedrock cut by feldspathic pegmitite dykes. The Duck Lake inflow #1 is centered by a narrow bed of marble flanked by gneiss meta-arkose and skarn. The main stream channel flows over the marble bedrock. The Moose Lake inflow #1 watershed is dominated by marble bedrock with biotite gneiss caps on the east-west trending ridges. The marble beds of Moose Lake inflow #1 contain considerable quantities of muscovite unlike the marbles in the watersheds discussed previously. The Paint Lake inflow #1 and Trading Bay inflow #1 watersheds have highly granitized biotite gneiss throughout their basins. The granitized biotite gneiss is cut by

feldspathic pegmatite dykes in both watersheds and additional quartz dykes are found in the Trading Bay inflow #1 basin. The Paint Lake inflow #1 feldspathic dykes are often several meters in width and host magnetite crystals.

The surficial geology for the export stream basin is given in Figures 34 through 41 and the percent areal extent in Table 16. The dolomite bedrock present in five of the export stream subwatersheds has been dispersed by glacial action in basal till over the silicate bedrock areas as well as the dolomite bedrock regions. Consequently all regions south of dolomite beds or in proximity to north-south trending beds have carbonate material present in the till fabric. For the purpose of this study, carbonate till deposits are those in which carbonate pebbles and boulders were frequently identified in the field. It should also be noted that silicate material always dominates over carbonate material in the till regardless of bedrock type. The dolomite beds which are located in central valleys due to differential weathering and glaciation processes are often overlain by relatively carbonate-free outwash and organic deposits which have no relationship to the underlying bedrock. Generally organic deposits occur in poorly drained depressions in till and outwash deposits or isolated bedrock pockets. The larger peat deposits overlay sand and in most cases are connected to a water body.

The surficial cover of Twelve Mile North inflow #1, Twelve Mile South inflow #1, Beech Lake inflow #1 and Duck Lake inflow #1 is dominated by carbonate till. The Beech Lake inflow #1 basin is drumlinized in the north-east corner and has an apparent higher clay content than other till observed. An esker of coarse sand and gravel traverses the Beech Lake inflow #1 basin from the north-east to the south-west. Peat deposits occupy the area between and around the two major ponds in the watershed.

The lower reaches of the Twelve Mile inflow #1 North and Twelve Mile inflow #1 South watersheds are sites of deep but spatially limited outwash sand and gravel deposits. The deposits are on the east

flank of a major outwash channel striking north-south along the central axis of Twelve Mile Lake.

The Moose Lake inflow #1 and Duck Lake inflow #1 basins are dominated by carbonate rich basal till which does not appear to have been reworked by water.

The Haliburton Lake inflow #12 watershed is composed of glacial outwash sand, gravel, and cobbles, deposited on the flank of a large north-south striking spillway down the central portion of Haliburton Lake.

The Head Lake inflow #1 subwatershed consists of a central peat accumulation surrounded by thin till. The peat accumulation occurs over large boulders which in turn overlay the bedrock.

Trading Bay #1 and Paint Lake #1 basin are gentle sloping minor till plains in the upper portions and extremely steep thin till in the lower sections.

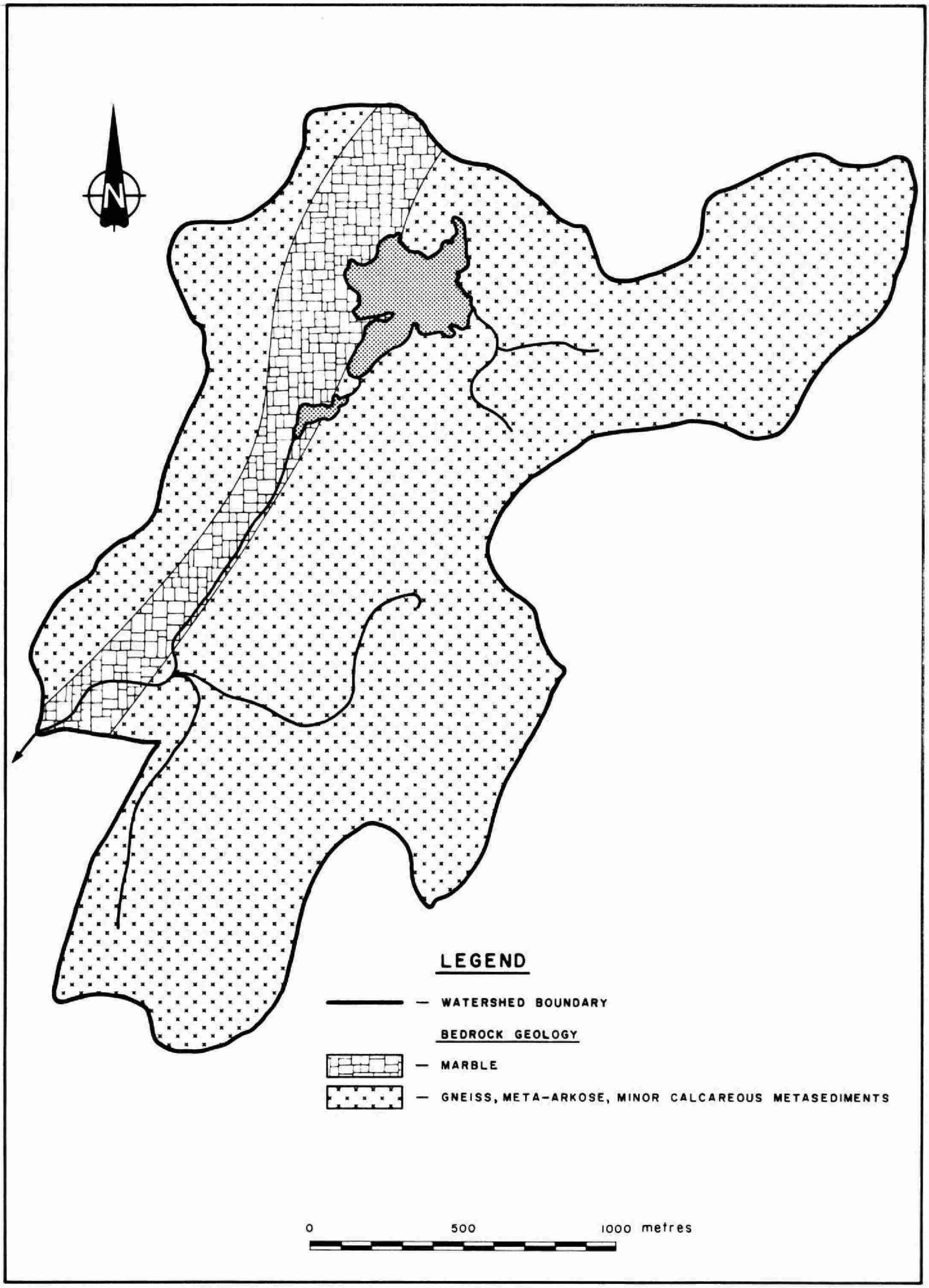

FIGURE 26 - BEDROCK GEOLOGY OF THE TWELVE MILE LAKE INFLOW Nº 1 (NORTH) "EXPORT" WATERSHED

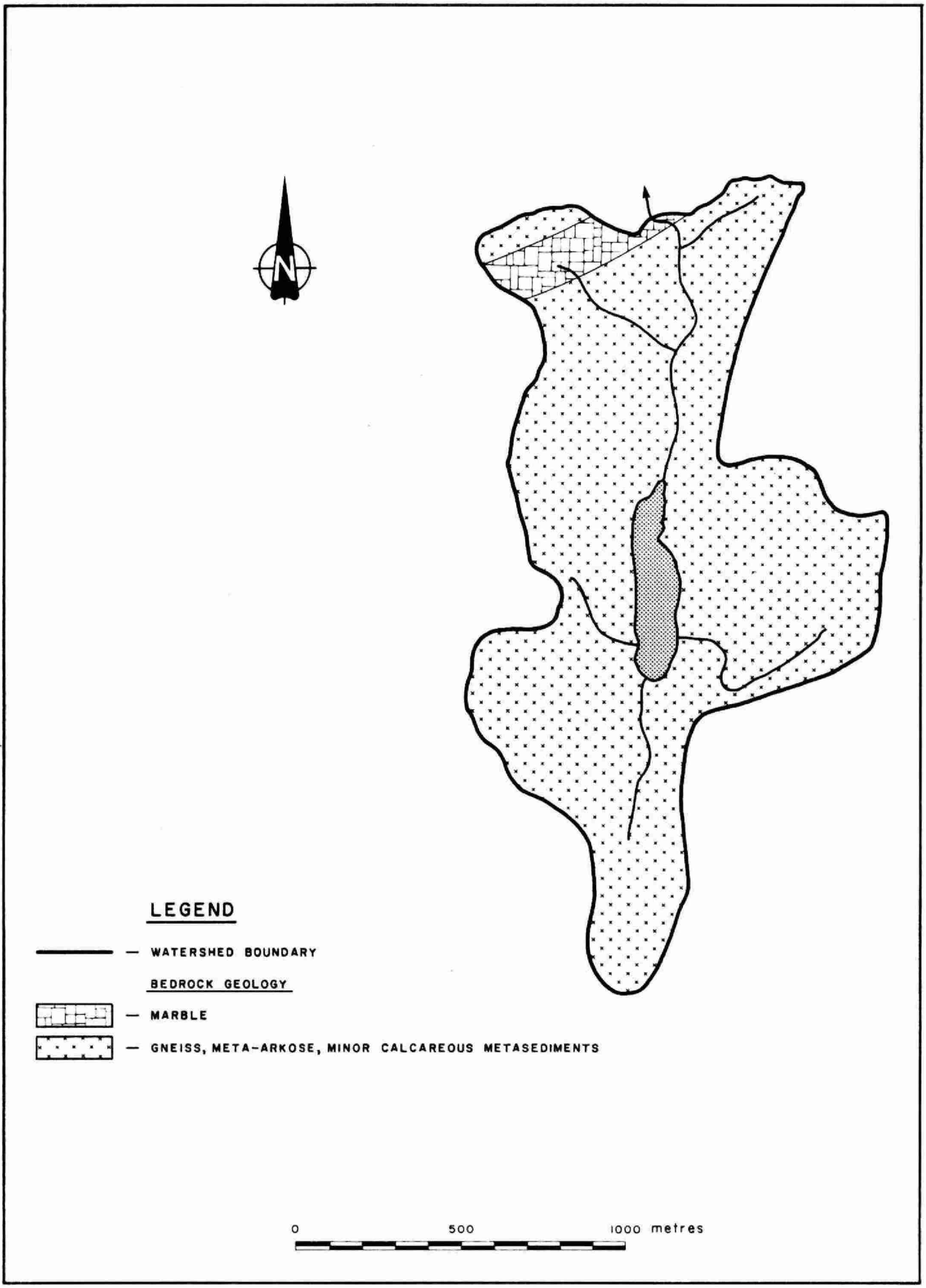

FIGURE 27 - BEDROCK GEOLOGY OF THE TWELVE MILE LAKE INFLOW Nº I (SOUTH) "EXPORT" WATERSHED

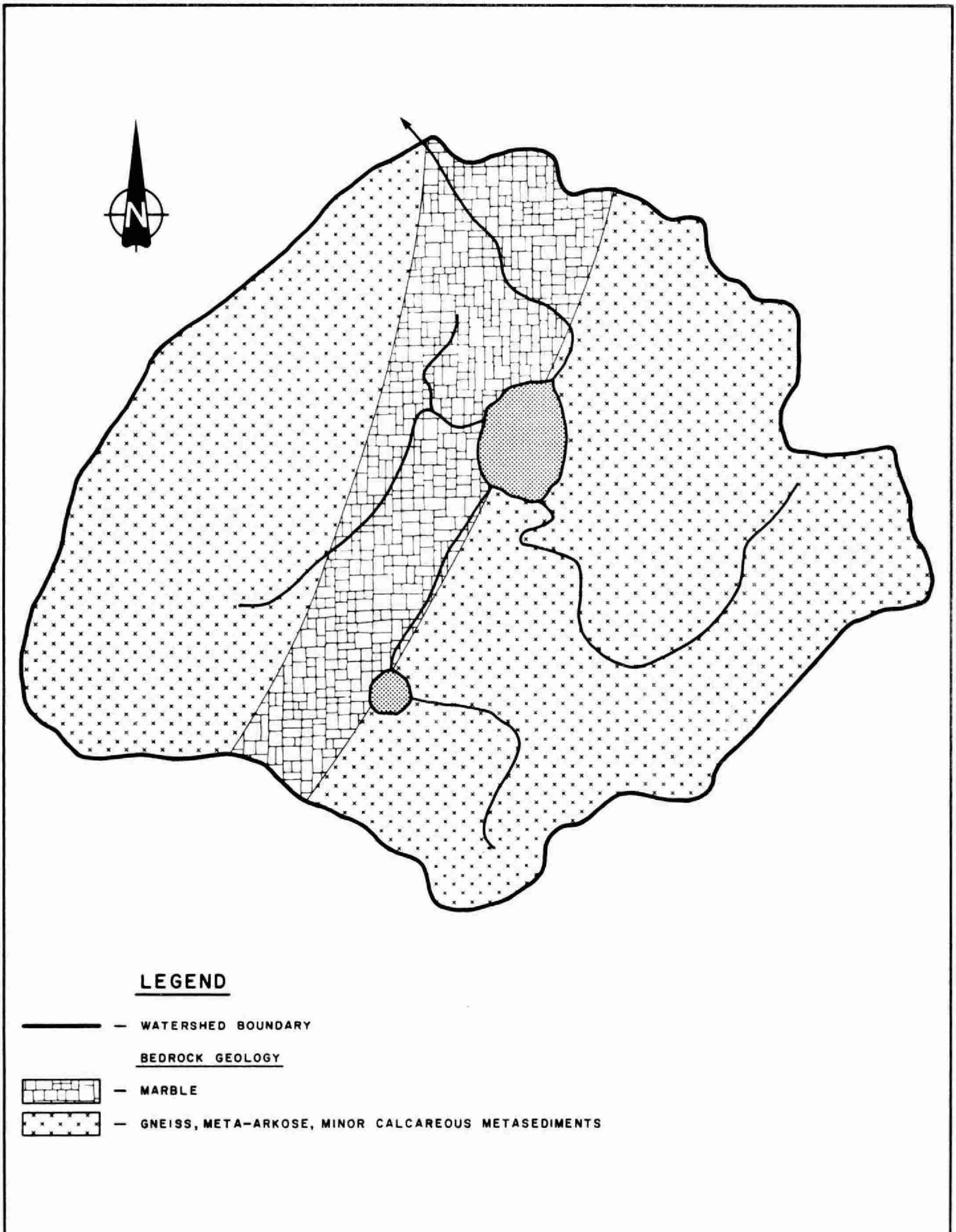

FIGURE 28 – BEDROCK GEOLOGY OF THE BEECH LAKE INFLOW Nº I "EXPORT" WATERSHED

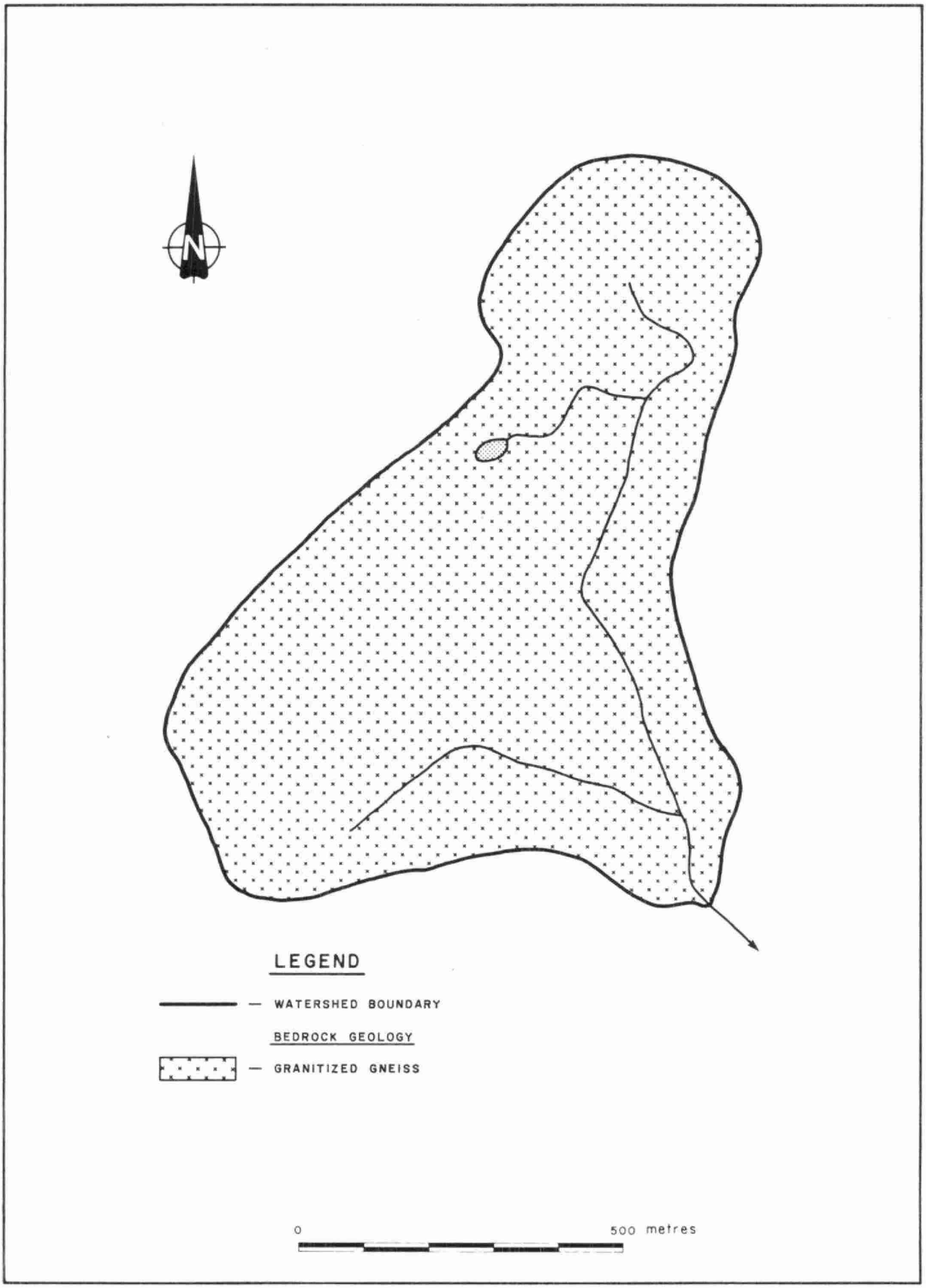

FIGURE 29 - BEDROCK GEOLOGY OF THE HALIBURTON LAKE INFLOW Nº 12 "EXPORT" WATERSHED

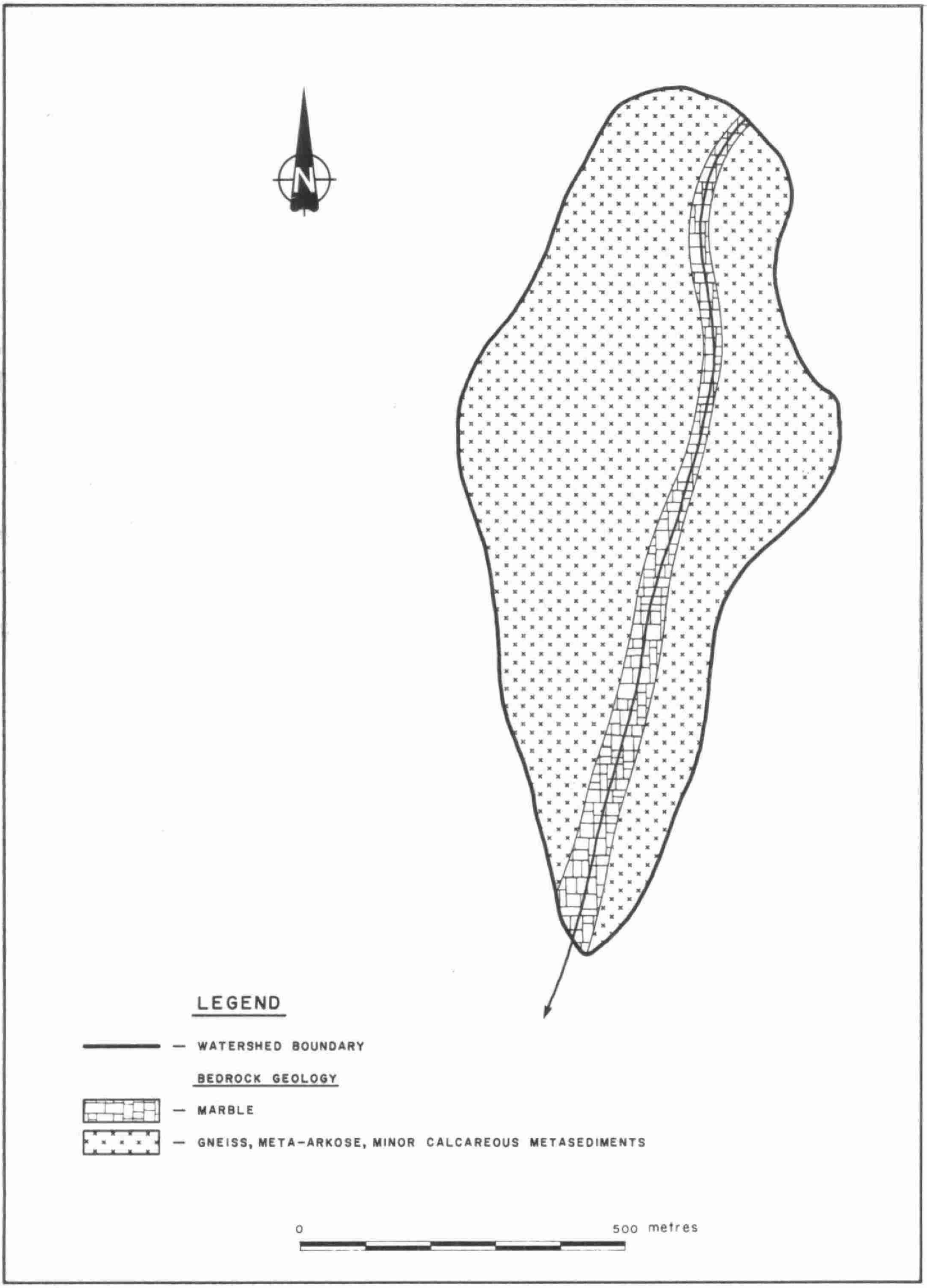

FIGURE 30 – BEDROCK GEOLOGY OF THE DUCK LAKE INFLOW N° 1 "EXPORT" WATERSHED

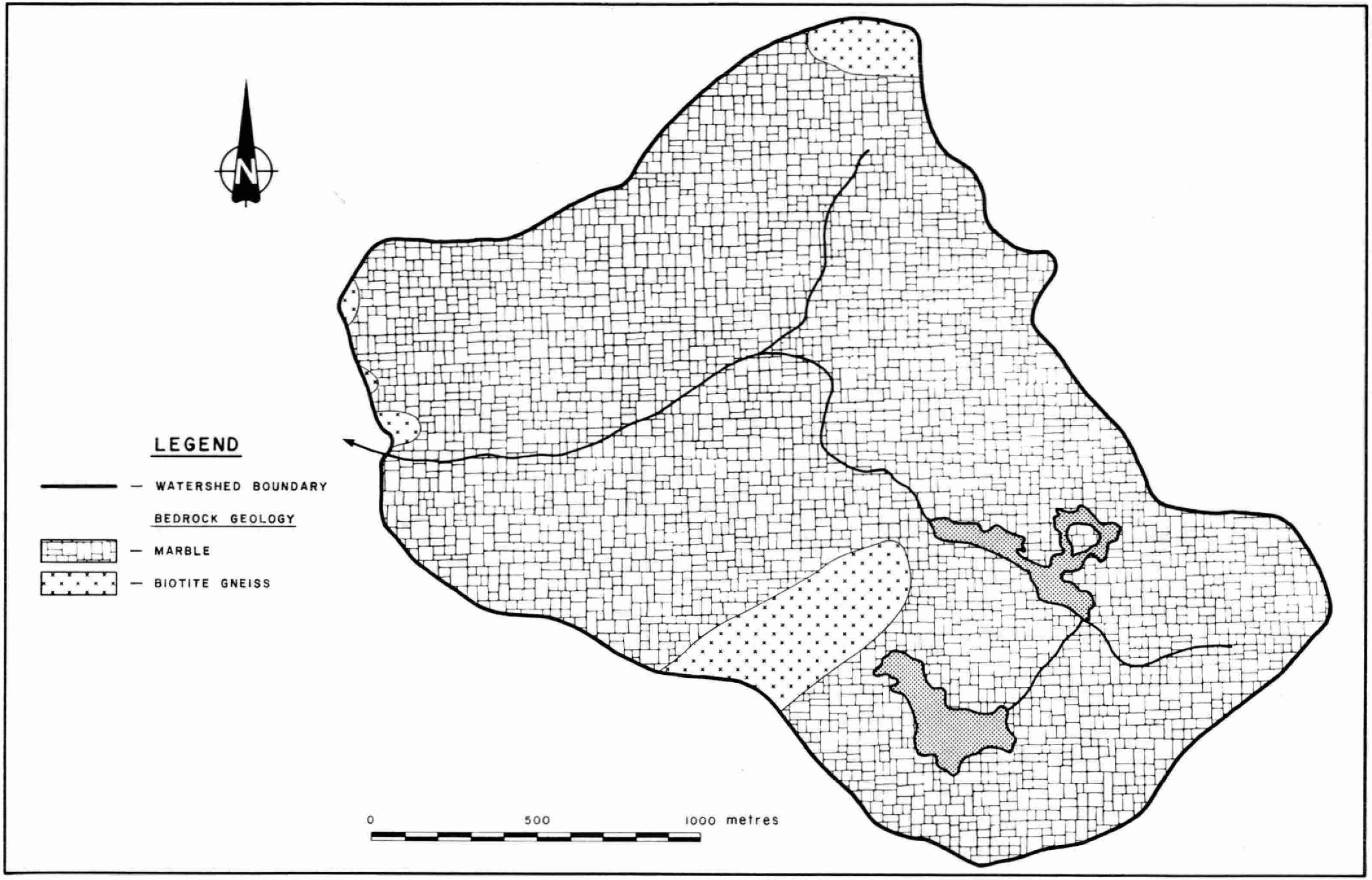

FIGURE 31 - BEDROCK GEOLOGY OF THE MOOSE LAKE INFLOW N°1 "EXPORT" WATERSHED

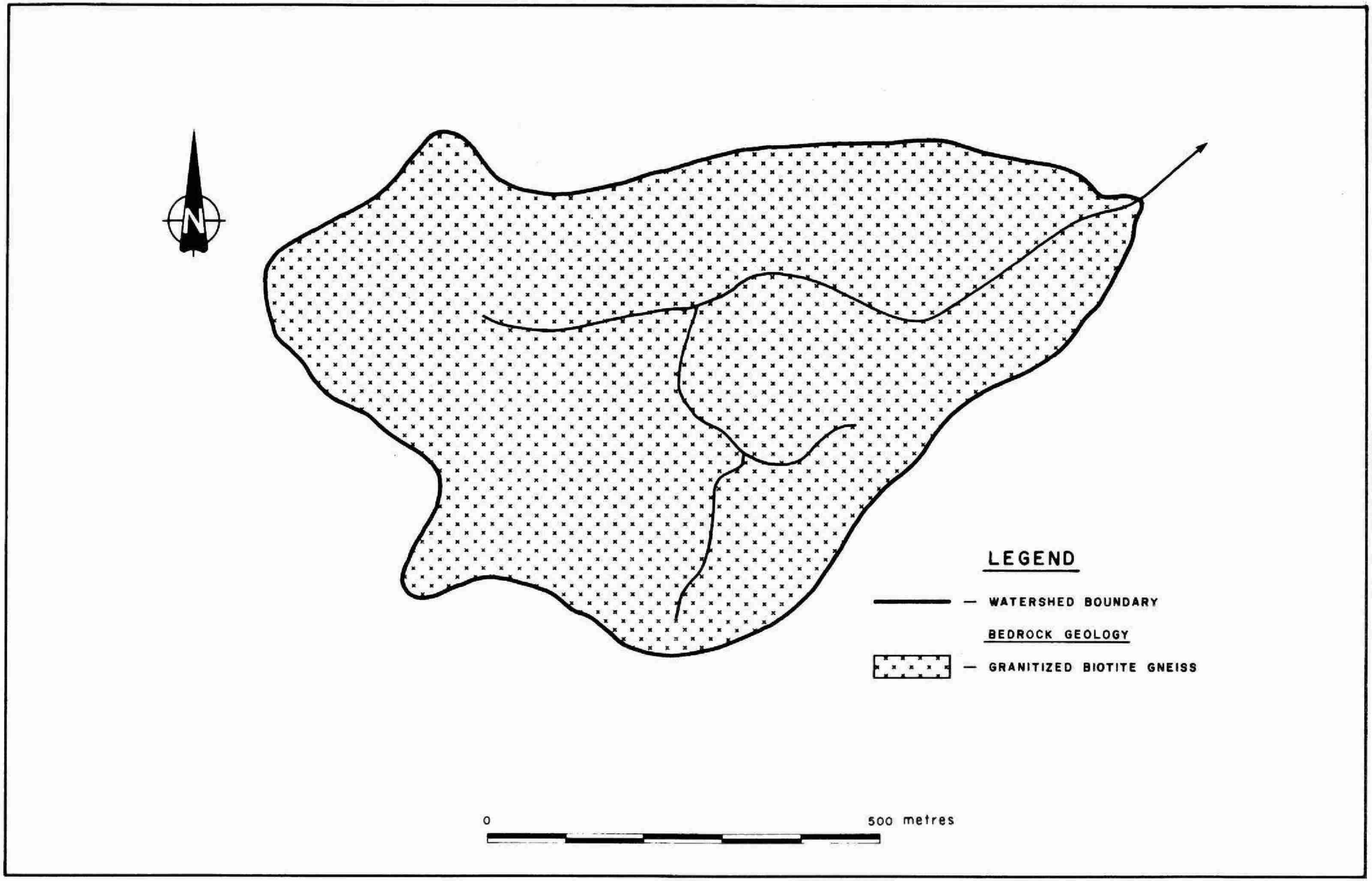

FIGURE 32 - BEDROCK GEOLOGY OF THE HEAD LAKE INFLOW Nº 1 (EAST) "EXPORT" WATERSHED

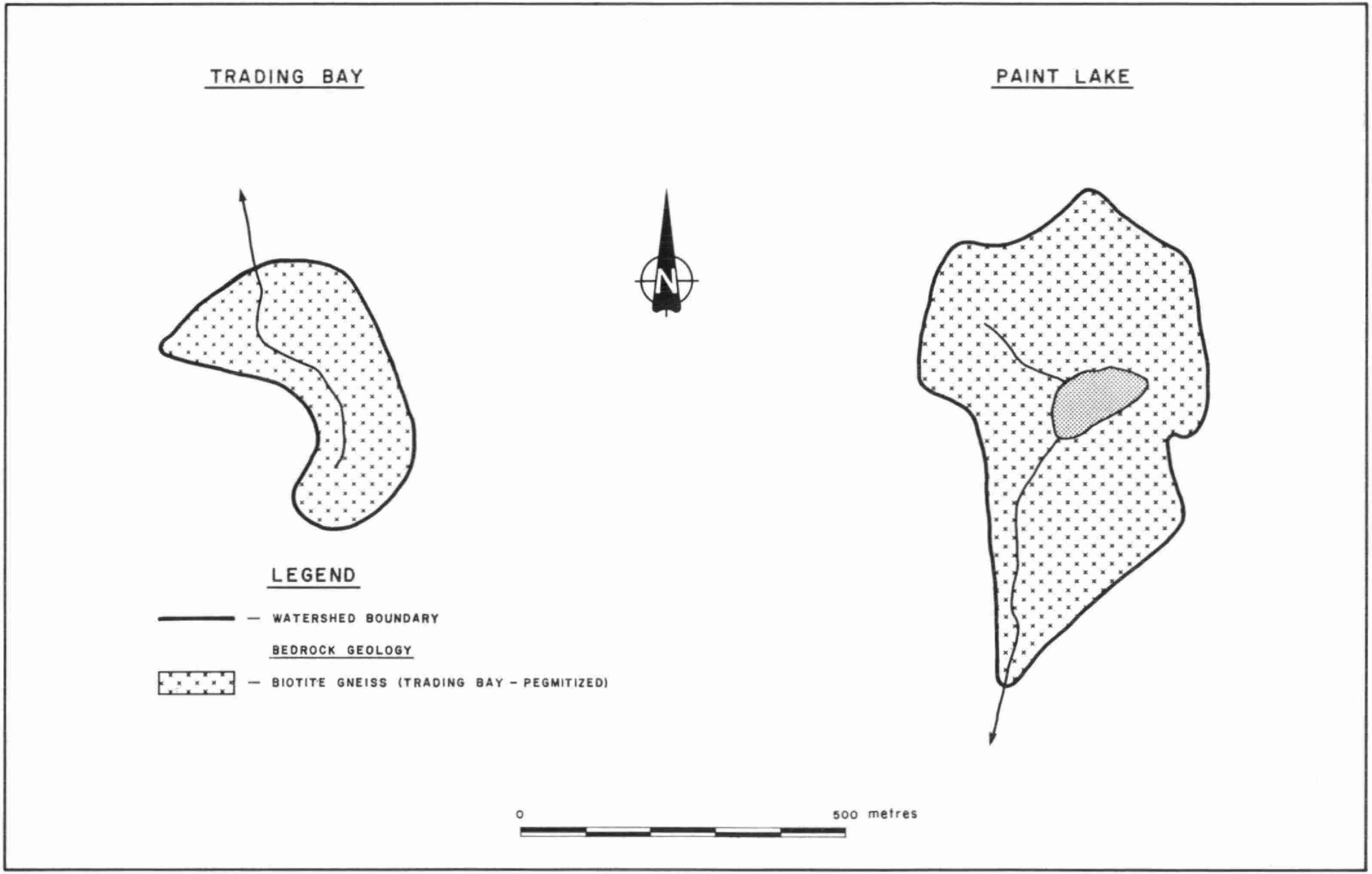

FIGURE 33 - BEDROCK GEOLOGY OF THE TRADING BAY AND PAINT LAKE INFLOW Nº I "EXPORT" WATERSHEDS

Table 15: Percent areal extent of bedrock types of the "export" stream watersheds.

Stream Name	Hornblende Biotite Gneiss	Diorite	Amphibolite & Shist	Migmitite	Amphibolite	Marble	Migmitite & Granite Intrusive	Gneiss & Shist	Gneiss & Skarn	Arkose & Minor Marble	Gneiss, Meta Arkose & Marble
Twelve Mile North Inflow #1	-	-	-	-	-	11.8	-	-	-	-	88.2
Twelve Mile South Inflow #1	-	-	-	-	-	2.2	-	-	-	-	97.8
Beech Lake Inflow #1	-	-	-	-	-	20.6	-	-	-	-	79.4
Haliburton Lake Inflow #12	100	-	-	-	-	-	-	-	-	-	-
Duck Lake Inflow #1	-	-	-	-	-	11.9	-	-	-	88.1	-
Moose Lake Inflow #1	5.9	-	-	-	-	94.1	-	-	-	-	-
Head Lake Inflow #1	100	-	-	-	-	-	-	-	-	-	-
Paint Lake Inflow #1	100	-	-	-	-	-	-	-	-	-	-
Trading Bay Inflow #1	100	-	-	-	-	-	-	-	-	-	-

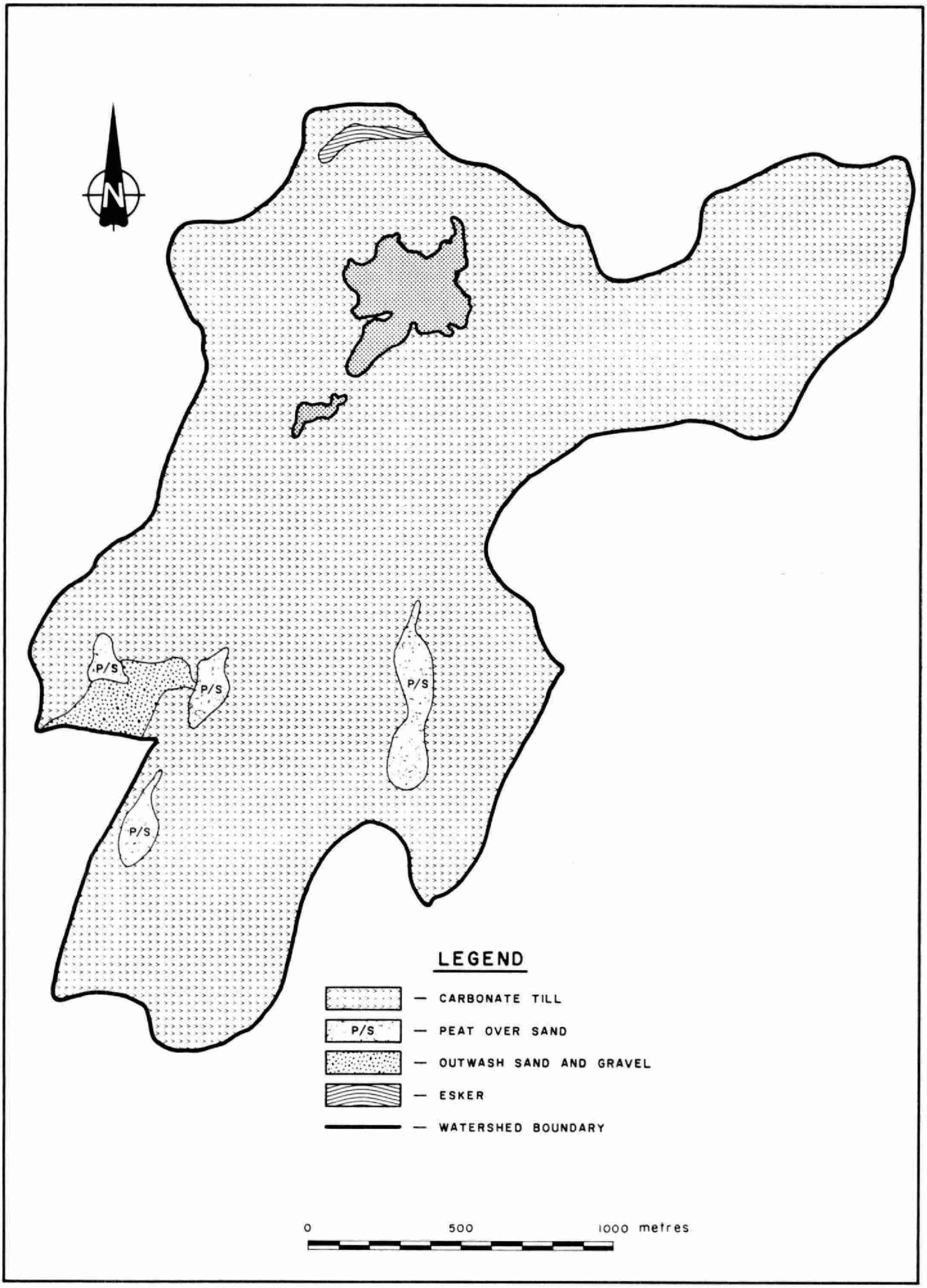

FIGURE 34 - SURFICIAL GEOLOGY OF THE TWELVE MILE LAKE INFLOW Nº I (NORTH) "EXPORT" WATERSHED

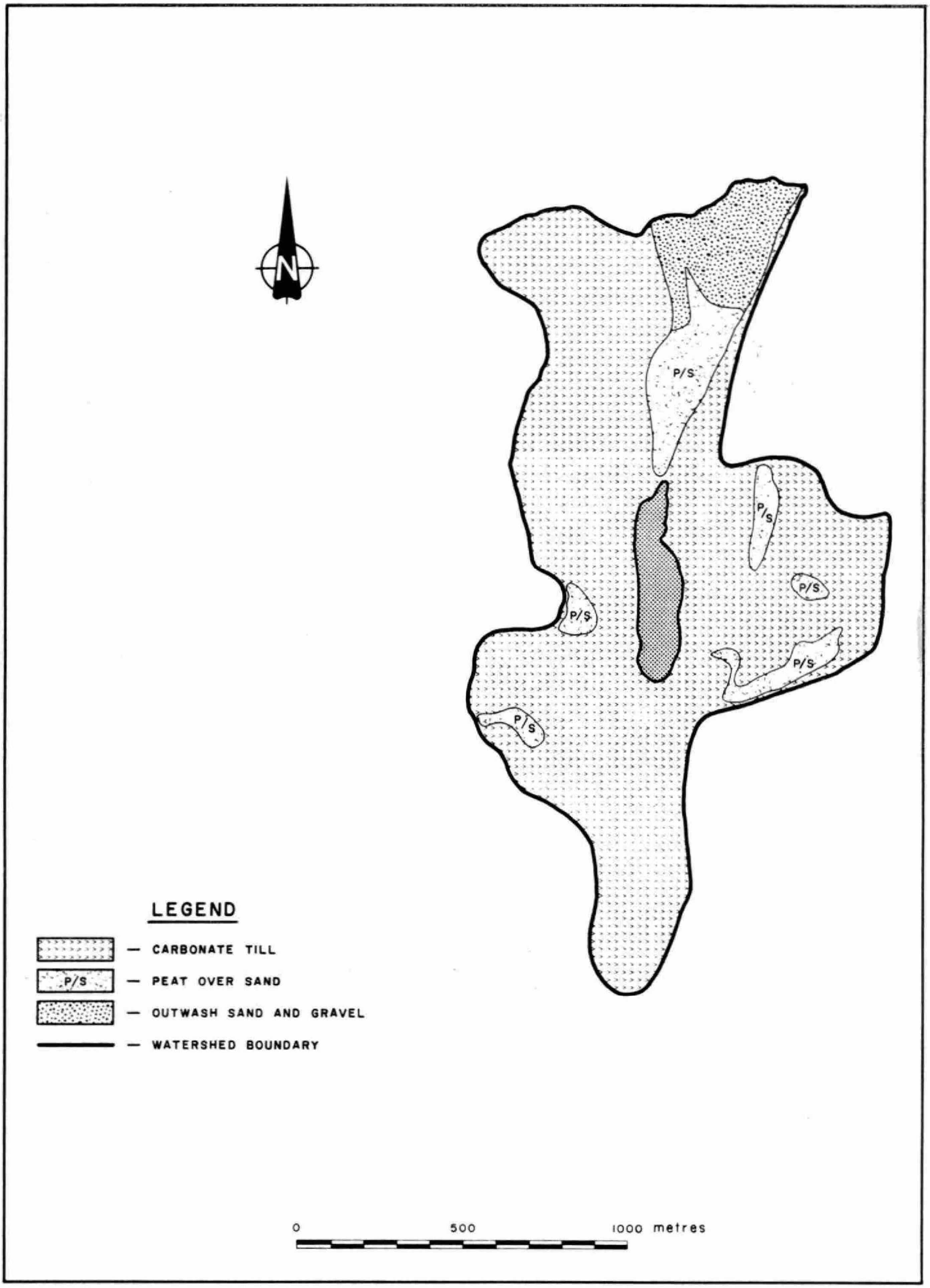

FIGURE 35 - SURFICIAL GEOLOGY OF THE TWELVE MILE LAKE INFLOW Nº 1 (SOUTH) "EXPORT" WATERSHED

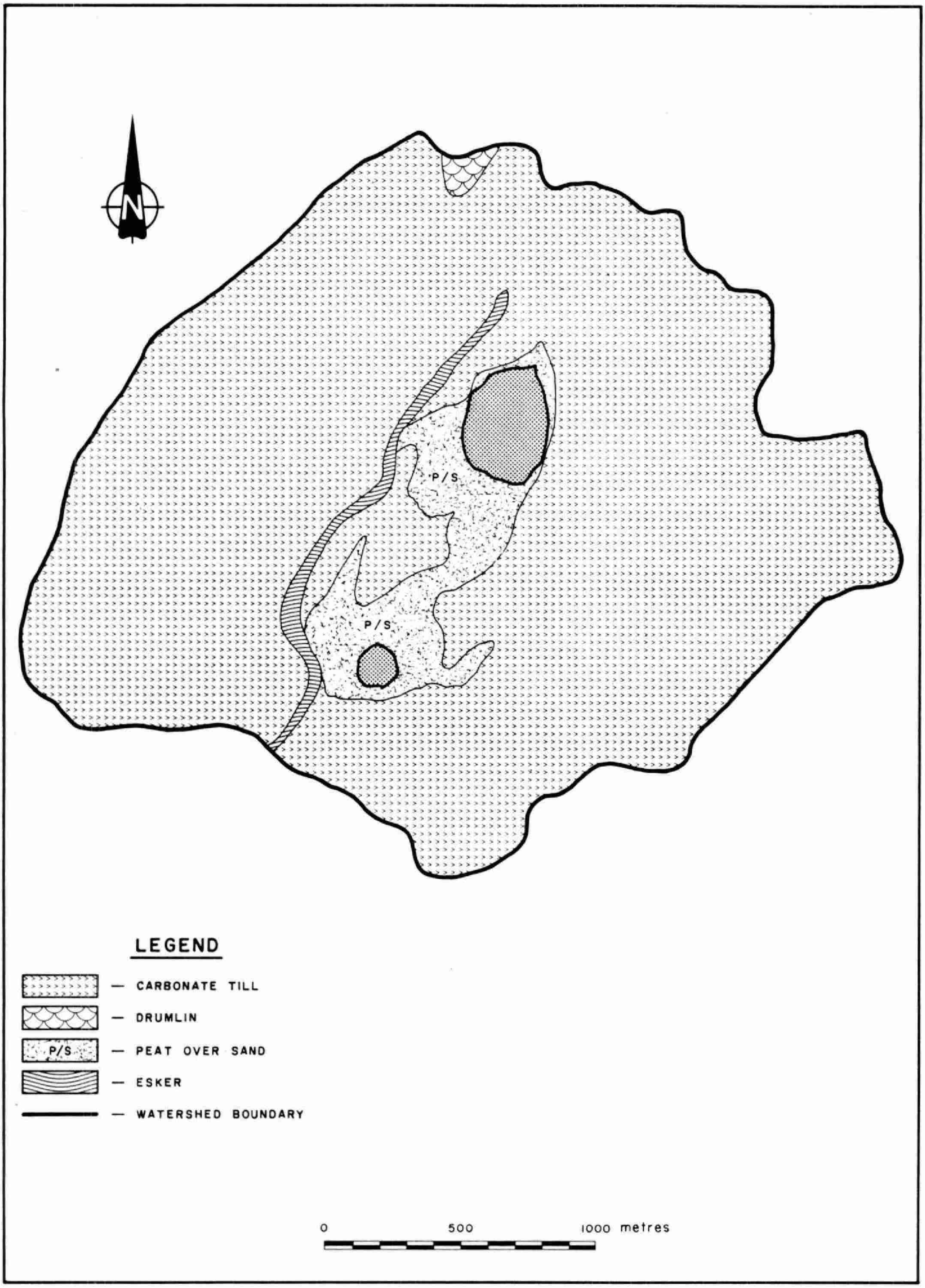

FIGURE 36 – SURFICIAL GEOLOGY OF THE BEECH LAKE INFLOW Nº I "EXPORT" WATERSHED

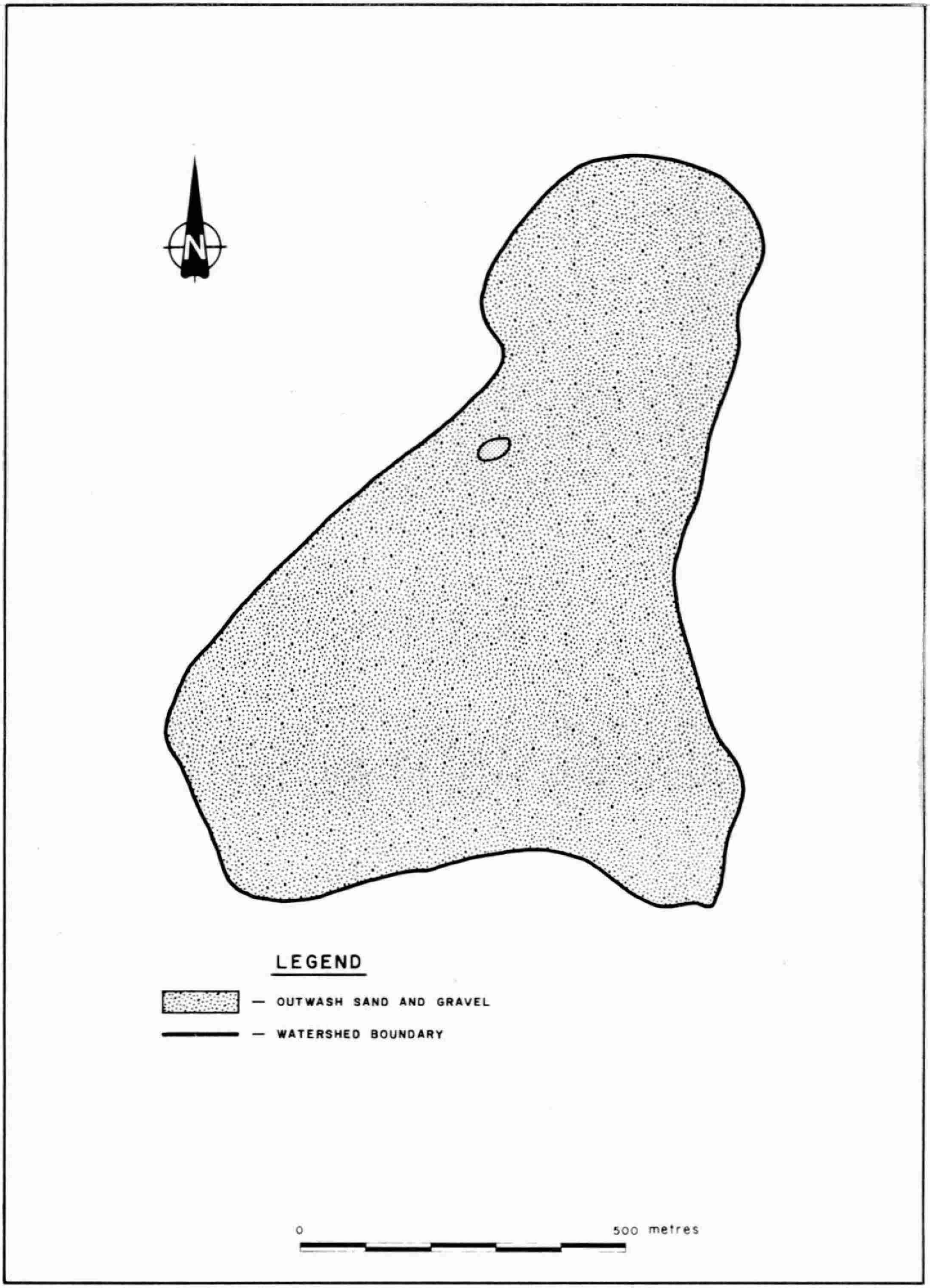

FIGURE 37 - SURFICIAL GEOLOGY OF THE HALIBURTON LAKE INFLOW
N° 12 "EXPORT" WATERSHED

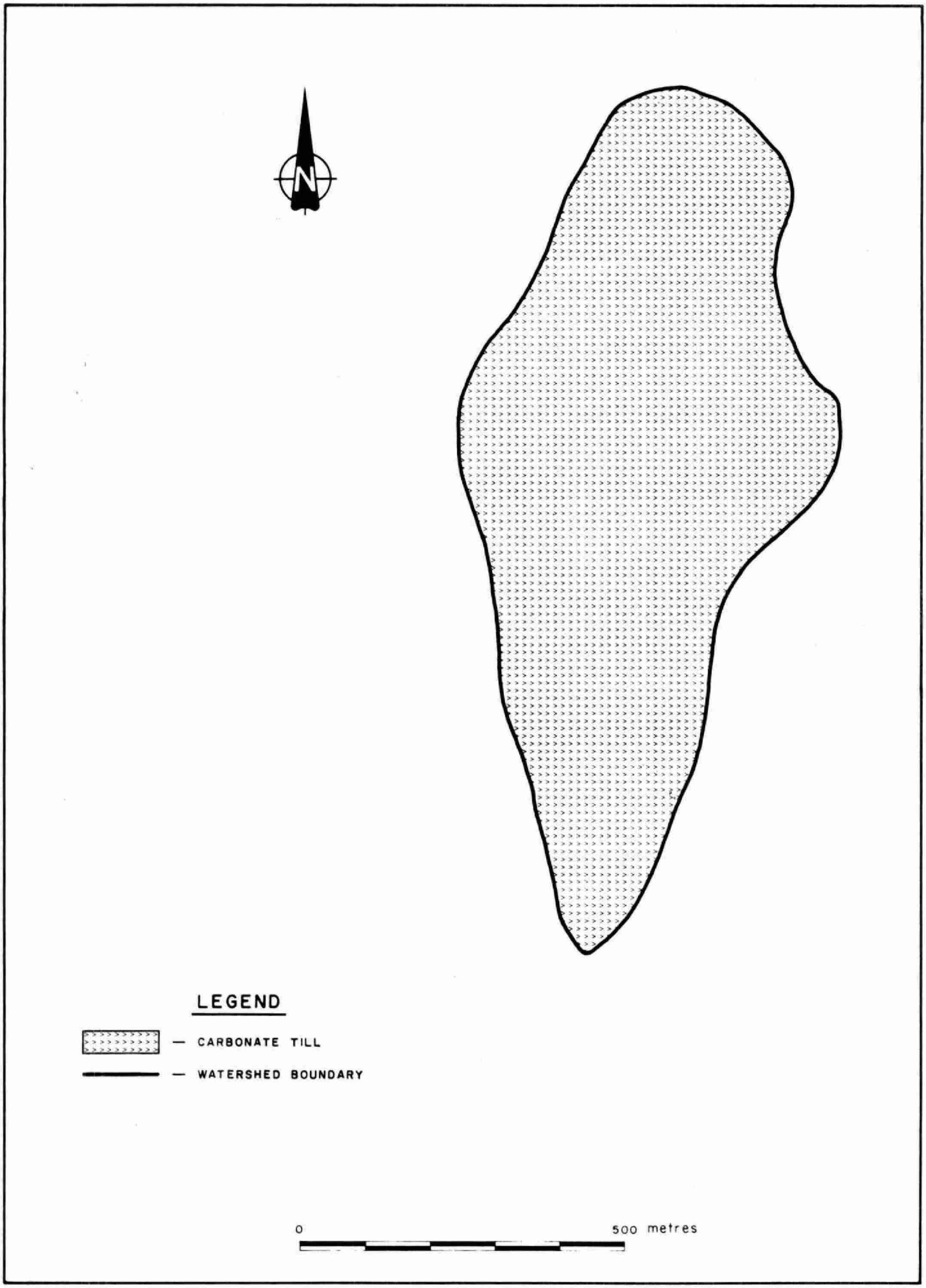

FIGURE 38 – SURFICIAL GEOLOGY OF THE DUCK LAKE INFLOW N°. 1 "EXPORT" WATERSHED

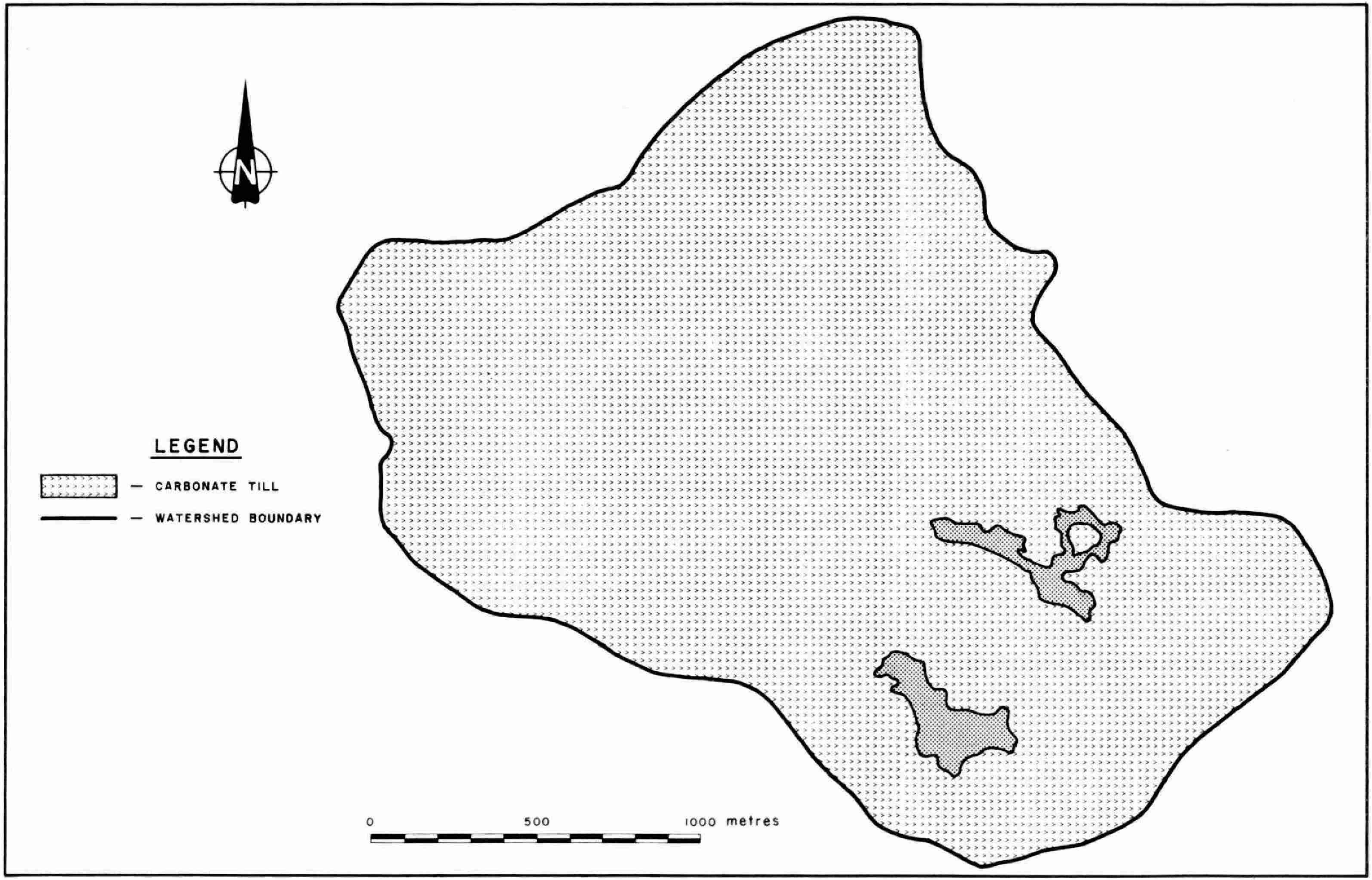

FIGURE 39 – SURFICIAL GEOLOGY OF THE MOOSE LAKE INFLOW Nº I "EXPORT" WATERSHED

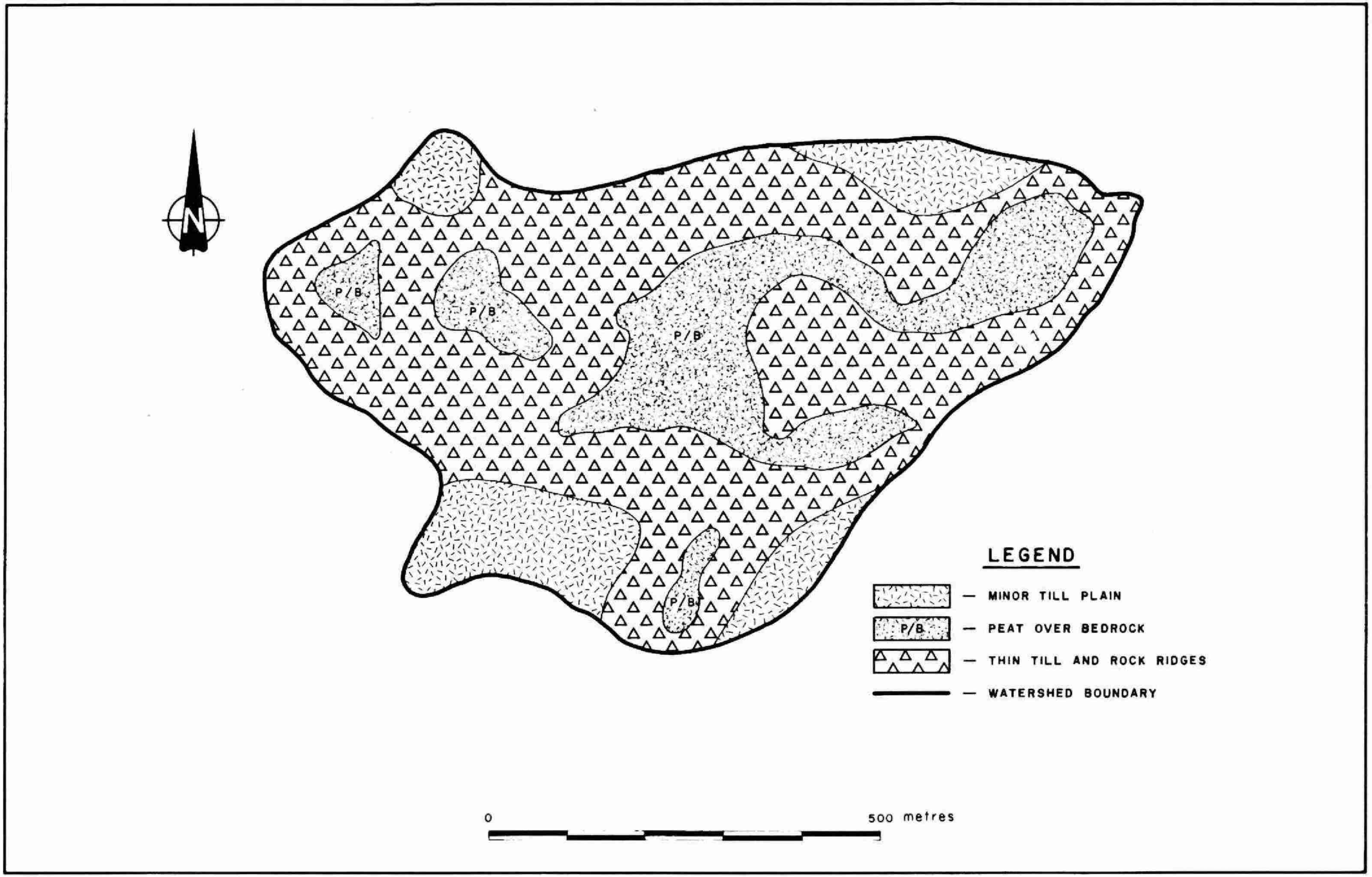

FIGURE 40 - SURFICIAL GEOLOGY OF THE HEAD LAKE INFLOW N°1 (EAST) "EXPORT" WATERSHED

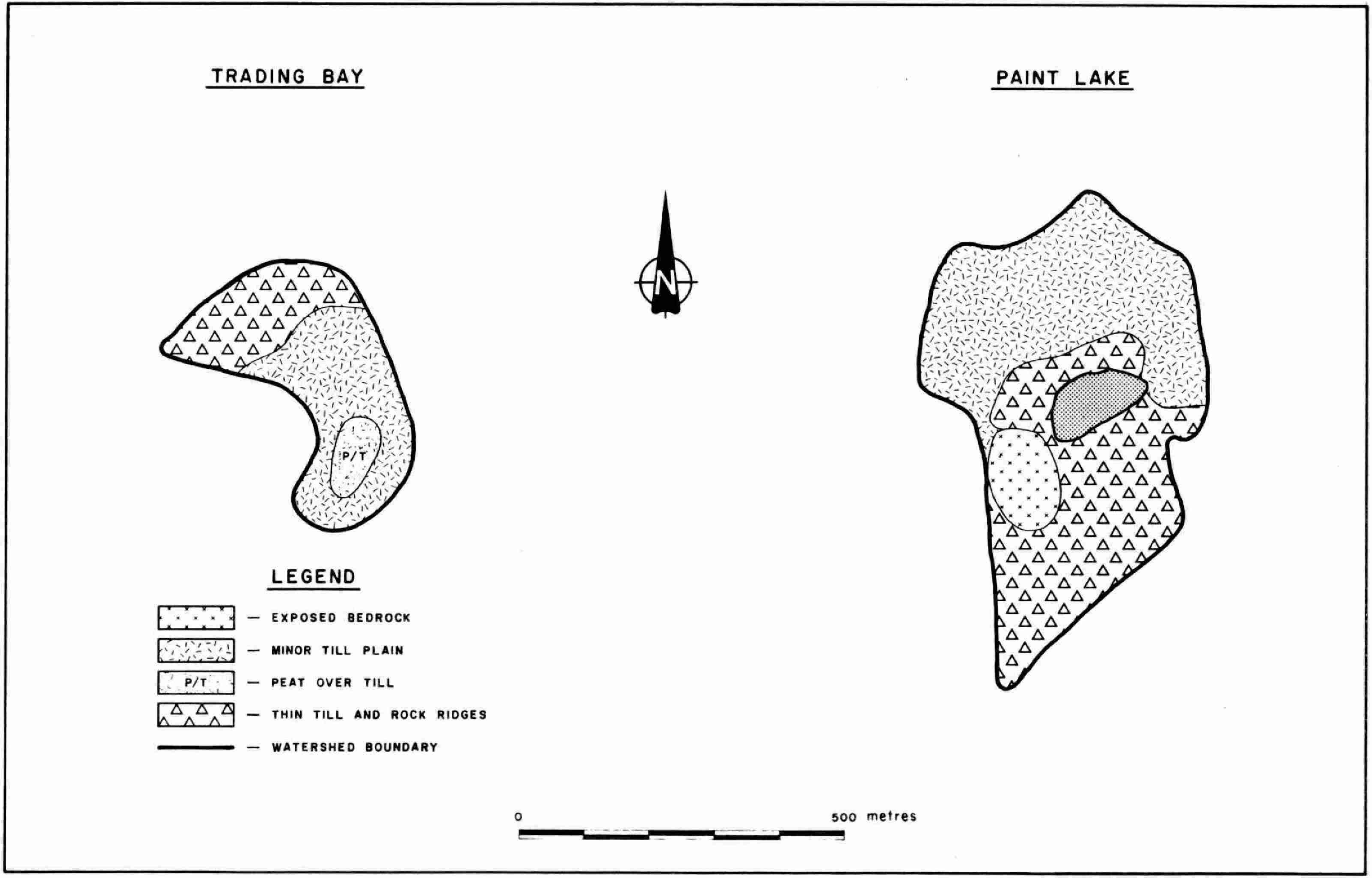

FIGURE 41 - SURFICIAL GEOLOGY OF THE TRADING BAY AND PAINT LAKE INFLOW Nº1 "EXPORT" WATERSHEDS

Table 16: Percent areal extent of surficial deposit types of the "export" stream watersheds.

Stream Name	Till (Carbonate)	Minor Till Plain	Thin Till and Rock Ridges	Peat	Bedrock	Outwash	Esker	Drumlin	Sand	Pond
Twelve Mile North Inflow #1	93	-	-	2.6	-	1.4	.1	-	-	2.9
Twelve Mile South Inflow #1	81.0	-	-	8.6	-	6.7	-	-	-	3.7
Beech Lake Inflow #1	89.3	-	-	6.9	-	-	1.5	.1	-	2.2
Haliburton Lake Inflow #12	-	-	-	-	-	100	-	-	-	-
Duck Lake Inflow #1	100	-	-	-	-	-	-	-	-	-
Moose Lake Inflow #1	97.2	-	-	-	-	-	-	-	-	2.8
Head Lake Inflow #1	-	13.8	64.2	22.0	-	-	-	-	-	-
Paint Lake Inflow #1	-	51.7	38.0	-	-	5.6	-	-	-	4.7
Trading Bay Inflow #1	-	55.6	35.5	8.1	-	-	-	-	-	-

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